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The five major research thrusts at the AI Center are described. They are as follows: Natural Language Processing; Machine Perception and Robotics; Task-Oriented Computer Animation; Programming Structures for Databases and Knowledge Bases; and Parallel Processing in AI. We have described these capabilities by combining some past work and directions of new work under progress.

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FINAL REPORT
ARTIFICIAL INTELLIGENCE (AI) CENTER OF EXCELLENCE
AT
THE UNIVERSITY OF PENNSYLVANIA

Army Research Office, Grant No: DAAG29-84-K-0061

October, 1989

1 Brief Historical Description of the Center and the Impact of the ARO Grant

The AI Center was established with the help of the ARO AI grant in June 1984. The ARO AI grant has made a major impact on our work in AI research and education. It has helped us to become a major center in AI, which is a resource to the nation as well as to the Army. The ARO AI grant has allowed us to attract the very best faculty and students, and provide them with state-of-the-art facilities for their research. We have recruited 12 new faculty: 4 senior and 8 junior. Part of Penn's attractiveness has clearly been the environment created by the AI Center. The establishment of the new laboratories (GRASP for vision and robotics; GRAPHICS for computer and graphics and graphics interfaces; LINC for natural language processing, knowledge representation, and expert systems, THEORY for the development of programming language environments for AI) have played a key role in the recruitment. At present, there are 23 faculty members and we have support from the administration to grow to 30 in the next 2–3 years and to 35 in the next 5–7 years. We have produced 34 Ph.D.s since 1984 in AI and AI-related areas, and in the next 2–3 years, we will be graduating about 6–7 Ph.D.s per year in the areas currently worked on in the AI Center, which span the GRASP, GRAPHICS, LINC, and THEORY Laboratories.

Our research in AI is highly integrated. Although there are major themes, there is a high degree of collaboration between various groups. Our work makes strong connections between symbolic and non-symbolic computation, as well as between applied and theoretical areas. It is based on solid mathematical foundations, empirical investigations, and experimental research involving system building; it depends heavily on the core areas of computer science. In this regard, our Center is, perhaps, unique in terms of our commitments to both theory and practice in AI. Our research in natural language processing, computer vision and robotics, computer graphics, database systems, and logic and computation has become world class, largely as a result of the enhanced environment (facilities, faculty and student support, and technical staff) created by the ARO AI grant. We have assembled strong groups in all these areas and plan to continue the growth of these areas plus some related areas, as well as strengthening the core computer science areas. Our close ties with Penn's Cognitive Science Program (an interdisciplinary activity between the disciplines of computer science, linguistics, philosophy, psychology, and mathematics (logic)) have been further strengthened by the activities of the AI Center. The AI Center at Penn has its impact not only on

computer science, but on a large segment of the University. In this sense, the AI Center is playing a unique role on the Penn campus.

In education, we have clearly made an impact in terms of the training of graduate students. We have also carried out an effective educational program for the Army, both in terms of in-house and on-site courses, both at the elementary and advanced levels.

2 What is Unique About the Center?

In the previous section, we have described some unique aspects of our AI work. In this section, we will state some unique characteristics of the Center itself.

A center-based research organizational structure is justified if it creates and sustains an environment in which researchers are able to generate new knowledge or create and produce technological innovations that they otherwise could not. What is the nature of the conditions that create such an environment? A clear case presents itself when the extent and/or cost of the facilities needed for the work are so great that they necessarily have to be shared. Other situations are where research teams are needed and/or have to be supported for extended periods of time. These cases present straightforward, valid justifications for the creation of a Center. There are, however, situations where justification for center-type support goes beyond needs for shared equipment. A prime case presents itself when (1) researchers in different areas share a problem and are both able and willing to bring their diverse skills to bear on different aspects of the same problem, and/or (2) they share different perspectives on the same or closely related topics.

These latter situations arise because researchers are often trained in some well-established areas, while the problems they wish to tackle go beyond those disciplines. This is the situation that characterizes our research in AI, and therefore, explains why center-type support has helped us to achieve our goals. Of course, for research in AI, shared facilities, both computer and network facilities and non-computer facilities, are also needed. A center-type structure is necessary, especially when the size of the activity goes beyond a certain level. We believe, however, that the necessity of building and sustaining an environment for providing the interaction described above is the central justification for a Center for research in AI. The Center structure also helps in coordinating the educational program for the Army, as it enables us to staff the courses with instructors whose research experience involves the type of interaction already described.

The ARO AI Center is a center because we share an intellectual framework of commonality in seeking to understand various interactive and cooperative human-computer systems. This commonality encourages the understanding and solution of genuine problems, not the search for problems which will simply verify or legitimize existing algorithmic techniques. Whether in robotics, computer vision, computer graphics, or natural language processing, we see the world as a place to be studied and analyzed, where computational solutions are developed without an inherent bias to promote a favorite method at all costs, whether really applicable or not.

An important consequence of the Center is the facilitation of novel Ph.D. work without the necessity of finding separate relevant funding beforehand. By supporting Ph.D. students in the last two years of their research, the Center provides an intellectual freedom which would be unavailable without coherent long-term support in generalized research areas. Ph.D. work usually forms the basis for continuing projects; thus while the individual efforts are, by necessity, strongly oriented toward particular dissertations, closer inspection will reveal the strong bonds in methodology and software between these studies. The investment in usable and documented tools is the result; research builds on the work of others rather than starting each project from scratch.

3 What are the Special Capabilities of the Center's Facilities?

The major research thrusts at the AI Center are as follows: (We have described these capabilities by combining some past work and directions of new work under progress).

1. **Natural Language Processing: Language and Speech**

   The University of Pennsylvania has an international reputation for its work in Natural Language processing. Together with colleagues in Linguistics, Philosophy and Psychology, we in Computer Science have made important discoveries in areas of language and speech as diverse as constrained grammatical systems, discourse processing and relations between sentence processing and discourse processing, conversational inference and linguistic pragmatics, the roles of planning and plan inference in cooperative interaction, and Natural Language acquisition (both formal studies of learnability and empirical studies of the relationship between perception and acquisition of lexical meaning).

   The research we are doing is directed towards providing a foundation for future computer systems that can exploit Natural Language in interacting with human users and in extracting information from unconstrained texts. The systems in question will have to be competent manipulators of both spoken and written language, as well as of graphics and animation.

   Handling spoken language makes new demands on Natural Language systems that cannot be satisfied by simply scaling up the current generation. Recent advances in low-level speech recognition techniques make it likely that within the next three to five years, systems will exist that will be able to automatically transcribe with reasonable accuracy, continuous speech by a particular, known speaker, with vocabulary sizes approaching five thousand words. However, there will still remain significant barriers to building systems which can understand naturally spoken text, even within closed domains. Such systems will face the same problems as a person given an accurate verbatim transcript of speech: people find such transcripts maddeningly difficult to read and understand.

2. **Machine Perception and Robotics: Exploration and Perceptual Development**

   Most past and present work in machine perception has involved extensive static analysis of passively sampled data, and the use of *a priori* knowledge represented by the designer for recognition purposes. But it is our opinion that this is the source of the rigidity and lack of robustness of most current recognition systems. First, it is clear to us that perception is not passive, but active. Biological systems are multisensory and active. Furthermore, even from an engineering point of view, one measurement is only enough to *form* a hypothesis. At least one other independent measurement is needed to *verify* it, unless very strong assumptions are made. Secondly, it is not clear to us that current representations of the form and substance of objects are really suited to analysis by a mechanistic system, such as a robot. In fact, we suggest the opposite, since such representations do not take account of the properties of the sensory apparatus that delivers the data to be matched against them. In principle, we believe that a robot must have a multitude of representations, since synthesis tasks, such as design and manufacture, make different representational demands than analysis tasks such as recognition. The point is to determine what these representational needs are and how to enable systems to use them and switch between them at will.

   The main goal of our research has been to determine what must be given to a robotic system and what it ought to derive from its measurements in order to function in an unstructured

and/or unknown environment. The result will be a robotic system with some built-in exploratory and data reduction procedures that can be used to acquire information about its environment — for example, the type of substances and the shapes of objects in its surround. This is what we call *machine perceptual development*, i.e., building representations for machine perception.

In this work, we are assuming a mobile robot, equipped with several sensors with controllable parameters, and with a set of exploratory and data reduction procedures. One important subtopic of this research is determining the minimal set of procedures necessary for building appropriate representations. Fundamentally, we are asking what is innate and what is developmental in the context of machine perception. It is our hypothesis that once the robot has acquired the above representations about its environment, it can then carry out more goal-directed tasks, such as manipulating objects or avoiding obstacles.

3. Task-Oriented Computer Animation

The availability of three-dimensional modeling techniques, high-speed hardware, and relatively low-cost computation has made the modeling and animation of human and robotic agents feasible for design assessment, human factors, task simulation, and human movement understanding. Human figure models have long been used in cockpit and automobile occupant studies; now they are finding application in vehicle and space station design, maintanence assessment, product safety studies, and computer animation for its own sake. Empirical studies of actual human motion provide natural motion highly specific to the subject and the experimental environment, but little theory of how such motion can be synthesized for use in animation.

Animation is a medium for communication. It must be understandable, unambiguous, and not misleading; convincing, yet easy to create. Producing such animation without an expert animator requires a computer system that understands tasks, motion, and their 'semantics'; in other words, a synthetic 'expert.' Our intention has been to extend the capabilities of the design engineer, the human factors analyst, or even the casual user to create, animate, and evaluate human performances. Especially in an engineering rather than artistic environment, users will need an effective motion design and analysis tool without feeling pressed to become overly involved in the mechanism of producing animations.

The overall goal of task-oriented figure simulation has been to produce usable interactive computational systems that behave, react, and appear as much as possible like actual people and robotic devices carrying out tasks.

4. Programming Structures for Databases and Knowledge Bases for AI

Our main goal has been the implementation, and experimentation with, new programming languages with a special emphasis on the representation of data and the implementation of knowledge bases for AI. Our current work has focussed on the underlying principles of typed and object-oriented languages, and we have recently embarked on the implementation of prototypes that demonstrate some extensions to these languages that increase their power and flexibility. There are two main ingredients to this research.

The first of these is the investigation of *flexible type systems*. Over the past twenty years, the development of programming languages has diverged into two almost independent branches. The first of these is the Algol/Pascal/Modula heritage of statically typed languages, whose type systems, while extremely useful as an aid to program correctness are regarded by many

as too inflexible. The second is the Lisp (and now Prolog) heritage in which most type-checking is performed dynamically. While these languages in this second group are generally regarded as excellent for "rapid prototyping", the lack of a static type system and a related structure of modules makes large programs in these languages much more difficult to control and prone to run-time bugs that could have been caught by a static type-checker. Recently we have seen the development of some new paradigms, notably *object-oriented languages* and *polymorphic* languages which indicate that the two streams of language development may converge. However the "types" in object-oriented languages are, for the most part, checked dynamically, and polymorphic languages, while their type systems are more expressive than those of the Algol/Pascal family, still lack certain features such as inheritance, which is an essential component of the object-oriented languages.

Recent research at Penn has demonstrated that there are ways to unify polymorphism with inheritance. Our goal has been to develop these ideas into a practical programming system with application to AI.

The second ingredient, *type systems for data and knowledge bases* is closely related to the first. On a larger scale, the development of databases and programming languages has also diverged. Nowhere is this more apparent than in the everyday task of writing database applications where the programmers have to be bi- or even tri- lingual. Code generally involves a host language, an embedded query language and a data definition language. Worse still, while the database schema and host language may individually be capable of representing and manipulating rich data structures, communication between the program and database is low-level, consisting at best of a channel in which accommodates only a small set of basic types such as integers, character strings etc.

Recent research at Penn has shown that, by combining sets with inheritance one naturally obtains (generalized) relations. This is closely related to the research on flexible types described above, and it is closely tied with the work in feature structures (information structures) in Natural Language Processing and Knowledge Representation in AI.

5. Parallel Processing in AI

Parallel processing, i.e., the development of parallel algorithms and architectures, has been an important aspect of our research. One reason is that parallel processing can lead to increased levels of performance in executing various AI tasks beyond those attainable in conventional sequential computers. A second reason is that parallel processing can provide the raw computing power needed to scale up the AI systems that we now have, e.g., in speech and natural language understanding, computer graphics, machine perception, and robotics. This is crucial in order for our systems to have access to large scale databases needed for scaling up. Finally, when we have reached the point at which integration of some of our AI systems becomes feasible, parallel processing is a potentially good way by which this can be achieved. In particular, a parallel or distributed operating system not only would realize such an integration but also promote concurrency and resource sharing among various tasks within and across different AI systems.

The overall goal of this research has been to determine whether the above reasons for exploiting parallelism in AI can in fact be justified in theory and practice. It is true that parallel processing research has reached the point at which actual parallel machines are being built and commercially sold, and parallel programming languages and applications software are beginning to be developed. However, these machines have, for the most part, been tuned for numerical applications. In contrast, AI applications usually rely on *symbolic* processing,

with "number-crunching" often relegated to low-level tasks (e.g., signal processing in low-level computer vision). Symbolic processing differs from numerical processing in that: (1) the former encodes and stores a large amount of information acquired from potentially many sources (e.g., images, speech and text), (2) the pieces of information are not only syntactically related but also semantically related, oftentimes in a very complex and dynamic manner, and (3) the processing of information involves operations (most notably, search) that are fundamentally different from numerical operations (e.g., matrix or FFT computations). Because of these differences, existing approaches to parallel processing for numerical applications may not be well-suited for AI applications.

In light of the above discussion, a systematic study of the role of parallelism in AI problem solving has been and is being carried out. In particular, new approaches to the following have been investigated: (1) techniques for designing parallel algorithms for problems that are fundamental to AI applications and (2) techniques for mapping the parallel algorithms to their optimal parallel architectures. More specifically, at present we are pursuing the following goals: (a) identification of *classes of algorithms* that are commonly used in AI problem solving and seek efficient parallel implementations; (b) development of general techniques for *deriving* an efficient parallel algorithm from a given *mathematical specification* of the problem; (c) *connectionist network* approach to knowledge representation and reasoning; (d) development of techniques for mapping parallel algorithms to their optimal parallel architectures; (e) investigation of programming, operating system and network issues for supporting distributed *real-time applications* such as multi-sensory systems.

4 Technology Transfer to Army, DoD in General, Government, and Industry

- **Army:**
  - Ben Cummings, HEL. Additional funding from the Human Engineering Lab at Aberdeen Proving Grounds comes directly to the Computer Graphics Research Lab. Their interests lie primarily in human simulation and performance evaluation applied to multi-operator vehicles, especially in reach, strength, workload, and cooperative behavior.
  - Mike Muuss, BRL. We have used BRL-CAD (a constructive solid geometry modeling and display system) and are constructing an interface between its geometric database and the human figure modeling systems we develop.
  - Joint Army/NASA A^3I Program, NASA Ames Research Center. The A^3I project is a simulation of all aspects of a helicopter mission. Our primary interest and involvement lie in the pilot model. We will be computing task load from the actual animation process which is itself driven by task simulation from mission simulators.
  - Pacific Northwest Laboratories, Battelle Memorial Labs, through Army research effort with Dugway. In this application we control an articulated robot mannequin used to test suit designs for permeability to chemical and biological agents. Primary interests lie in animation control, safe path determination, collision avoidance, and motion feasibility.
  - Harlan Black, Ft. Monmouth. We have a STAS contract to assist in the human interface and semantic design of ARES, an interactive graphical system to aid in corps level tactical planning.
  - Jude Height, Aberdeen Proving Ground, who is interested in object oriented languages.
  - Joe Psotka (Army Research Institute), who is interested in our work in graphics and animation, natural language, and database/knowledge base systems.
  - Mort Hirschberg (BRL) is interested in natural language and expert systems.
  - Engineering Topographic Lab, Ft. Belvoir, computer vision work.
  - Izak Fajerman (Ft. Monmouth, NJ), who is interested in Army intelligence and AI.
  - Colonel Calvin Boyles and Dr. Dean, (Fort Huachuca, AZ), Army intelligence and AI.
  - Major Mark Biludean, (United States Military Academy, West Point, NY), AI Education Program in general.
  - Phil Emmerman, Harry Diamond Laboratories, Adelphi, MD, man-machine interfaces, natural language interfaces.
  - Center for Intelligent Control Systems, MIT, Cambridge, MA.
- **DoD in general:**
  - We have several research contracts from AFOSR, ONR, and DARPA.
- **Government:**
  - U.S. Post Office
  - IRS

- **Industry:**
  - BBN (Bolt, Beranak, and Newman), Cambridge, MA — Natural Language Processing.
  - SRI, International, Menlo Park, CA — Natural Language Processing.
  - HP Labs, Palo Alto, CA — Natural Language Processing.
  - Boeing-Vertol, Media, PA — Animation, Graphics.
  - RCA Fed System Division, Morristown — Animation, Graphics.
  - General Motors (Defense Systems Division), Detroit, MI — Animation, Graphics.
  - McDonnell-Douglas Helicopter — Animation, Graphics.
  - AT&T Bell Labs, Murray Hill, NJ — Programming Languages and Knowledge Bases, Natural Language Processing.
  - GE, Schenectady, NY — Natural Language Processing.
  - Siemens Computer, NJ — Natural Language Processing.
  - Xerox Palo Alto Research Center, Palo Alto, CA — Natural Language Processing.
  - DuPont, Wilmington, DE — Vision and Robotics.

5 Interaction with Army/DoD Personnel and Other Significant Visitors

- **Significant Visitors:**
  - James Fletcher, NASA
  - Ben Cummings, Director Human Engineering Labs, Aberdeen
  - James Martzell, Army—NASA A3I project
  - Earl Alluisi, Pentagon
  - Mike Muuss, BRL
  - Harlan Black, Ft. Monmouth
  - Jude Height, Aberdeen Proving Ground
  - Joe Psotka, Army Research Institute
  - Dr. Jay R. Scully, Assistant Secretary of Army
  - Dr. Saul Amarel, former Director of ISTO at DARPA, now at the Rutgers University.
  - John Rittenhouse, Executive Vice President, GE, Valley Forge, PA.
  - Professor Richard Karp, University of California, Berkeley
  - Professor Allen Newell, Carnegie-Mellon University
  - Professor Donald Knuth, Stanford University
  - Professor Nils Nilsson, Stanford University
  - Professor Anil Nerode, Cornell University, Director, Army Math Institute
  - Professor Herb Simon, Carnegie-Mellon University
  - Professor Willem Levelt, Max Planck Institute of Psycholinguistics, Nijmegen, The Netherlands

- Professor George Miller, Princeton University
- Dr. Ray Perrault, SRI International, Director AI Center
- Dr. Lauri Karttunen, Xerox, Palo Alto Research Center
- Representative William Gray, PA
- Governor Robert Casey, PA

6 List of Participating Faculty: July 1984 – Sept. 1989

Norman Badler
Ruzena Bajcsy
Val Breazu-Tannen
Peter Buneman
Susan Davidson
Jean Gallier
Sam Goldwasser
Carl Gunter
Aravind Joshi
Insup Lee
Mitch Marcus
Dale Miller
Max Mintz
Michael Palis
Lokendra Shastri
Mark Steedman
Bonnie Webber
K. Wohn

7 Ph.D. Graduates (AI and AI Related) (1984 — Sept. 1989)

GRAD	NAME	DISSERTATION TOPIC	FIRST POSITION
Ph.D. Recipients 1989			
May 89	**Pearl Pu**	"Qualitative representation and simulation of ordinary and intermittent mechanical mechanisms" Advisor:Badler	Assistant Professor, University of Connecticut
Ph.D. Recipients 1988			
May 88	**Amy Zwarico**	"Timed Acceptances: An Algebra of Time Dependent Computing" Advisor:*Lee*	Assistant Professor, Johns Hopkins University
Aug 88	**Greg Hager**	"Active Reduction of Uncertainty in Multi-sensor Systems" Advisor:*Mintz*	Fulbright Scholar, Fraunhofer-Institute für Informations and Datenverarbeitung, Karlsruhe, FRG
Aug 88	**Stephane Mallat**	"Multiresolution Representations and Wavelets" Advisor: *Bajcsy*	
Aug 88	**Wayne Snyder**	"General E-Unification" Advisor:*Gallier*	Assistant Professor, Boston University
Dec 88	**Robert Kass**	"Acquiring a Model of the User's Beliefs in a Cooperative Advisory Dialogue" Advisor:*Finin*	Senior Research Engineer, Center for Machine Intelligence, Ann Arbor, MI
Dec 88	**Ethel Schuster**	"Generating pronominal reference to events and actions" Advisor: *Webber*	Assistant Professor, Swarthmore College
Dec 88	**Dennis Shea**	"Parallel Computer Architecture: A Scalability Analysis" Advisor:*Ma*	Manager, IBM Research, Yorktown Heights, NY
Dec 88	**Raymond Watrous**	"Speech Recognition Using Connectionist Networks" Advisor:*Shastri*	Visiting Assistant Professor, University of Toronto, Canada
Dec 88	**David Weir**	"Characterizing Mildly Context-Sensitive Grammar Formalisms" Advisor:*Joshi*	Assistant Professor, Northwestern University

Ph.D. Recipients 1987

May 87	**Russ Anderson**	"Real Time Expert Systems to Control a Robot Ping Pong" Advisor: *Paul*	AT&T Bell Labs, Holmdel, NJ
May 87	**Eric Krotkov**	"Exploratory Visual Sensing for Determining Spatial Layout with an Agile Stereo Camera System" Advisor: *Bajcsy*	Post-doctoral student at *Laboratoire d'Automatique et d'Analyse des Systemes*, Toulouse, France
May 87	**Sitaram Lanka**	"Aid to Database Design: An Inductive Inference Approach" Advisors: *Joshi*	Assistant Professor, Pennsylvania State University
May 87	**Gopalan Nadathur**	"A Higher-Order Logic as the Basis for Logic Programming" Advisor: *Miller*	Assistant Professor, Dept. of Computer Science, Duke University
May 87	**David Smitley**	"The Utilization of Processors Interconnected with an Optical Network" Advisor: *Lee*	Supercomputing Research Center, Lanham, MD
Dec 87	**Bhagirath Narahari**	"An Integrated Analysis of Algorithms and Interconnection Networks" Advisor: *Ma*	Assistant Professor, University of Washington
Dec 87	**Stan Raatz**	"Aspects of a Graph-Based Proof Procedure for Horn Clauses" Advisor: *Gallier*	Assistant Professor, Rutgers University
Dec 87	**Sharon Stansfield**	"Visually-Guided Haptic Object Recognition" Advisor: *Bajcsy*	Member, technical staff, Sandia National Labs
Dec 87	**David Heeger**	"Models for Motion Perception" Advisor: *Bajcsy*	Post-doctoral student at Arts & Media Tech. Lab at MIT
Dec 87	**Shiow-Chuan Lin**	"Performance of Dynamic Computer Networks: A Sensitivity Analysis" Advisor: *Ma*	AT&T Bell Labs, Holmdel
Dec 87	**K. Vijayshankar**	"A Study of Tree Adjoining Grammars" Advisor: *Joshi*	Assistant Professor, University of Delaware

Ph.D. Recipients 1986

May 86	**Paul A. Fishwick**	"Hierarchical Reasoning: Simulating Complex Processes Over Multiple Levels of Abstraction" Advisor:*Badler*	Assistant Professor, Department of Computer Science, University of Florida
May 86	**Tamar Granor**	"A User Interface Management System Generator" Advisor:*Badler*	Adjunct Assistant Professor, Dept. of Computer Science, University of Pennsylvania
May 86	**Martha Pollack**	"Goal Inference in Expert Systems" Advisor: *Webber*	AI Center, SRI International, Menlo Park, CA.
Aug 86	**Hugh Durrant-Whyte**	"Integration, Coordination and Control of Multisensor Robot Systems" Advisor:*Paul*	Assistant Professor, Oxford University, Cambridge, England

Ph.D. Recipients 1985

Jan 85	**Kathleen McCoy**	"Correcting Object-Related Misconceptions" Advisor:*Joshi*	Assistant Professor, Dept. of Computer Science, University of Delaware, Newark, DE
Jan 85	**Peter Allen**	"Object Recognition From Vision and Touch" Advisor:*Bajcsy*	Assistant Professor, Dept. of Computer Science, Columbia University, NY
Jan 85	**Julia Hirschberg**	"A Theory of Scalar Implicature" Advisor: *Webber*	AT&T Bell Labs, Murray Hill, NJ
Jan 85	**Steve Platt**	"A Structural Model of the Human Face" Advisor:*Badler*	Assistant Professor, Dept. of Computing, Swarthmore College, PA

Ph.D. Recipients 1984

Jan 84	**Hassan Ait-Kaci**	"A Lattice Theoretic Approach To Computation Based On A Calculus of Partially-Ordered Type Structures" Advisor: *Buneman*	MCC Corporation, Austin, TX
Jan 84	**William Dowling**	"Contributions To An Algebraic Framework for Solutions to the Compiler Correctness Problem" Advisor: *Gallier*	Assistant Professor, Dept. of Computer Science, Drexel University, Philadelphia, PA
Jan 84	**Eric Mays**	"A Model Temporal Logic for Reasoning About Changing Database with Applications to National Language Question Answering" Advisor: *Joshi*	IBM, Yorktown Heights, NY
Jan 84	**Rishiyur Nikhil**	"An Incremental Strongly Typed Query Language" Advisor: *Buneman*	Assistant Professor, Dept. of Computer Science, MIT, Cambridge, MA
Jan 84	**James Korein**	"A Geometric Investigation of Reach" Advisor: *Badler*	IBM, Yorktown Heights, NY

8 List of Publications: July 1984 – Sept. 1989

Abstracts of Technical Reports Published, to Appear, or Submitted for Publication During Report Period

What Can We Learn From One Finger Experiments?
Rusena Bajcsy, David Brown
Jeff Wolfield, Dan Peters
Technical Report MS-CIS-83-03
Grasp Lab 01

This paper describes results from recent experiments performed in our laboratory with two different tactile sensors attached to a cartesian coordinate system. The one sensor is in the form of a flat surface equipped with an array of 8 by 8 strain-gage sensors on loan from the Lord Corp., USA. The other sensor is in the form of a rigid finger of an octahedron tapered with four sides and ended with one tip. All together the device has 133 pressure sensors. This device was obtained as part of US-French collaboration from LAAS Toulouse, France (Dir., Prof. G. Giralt).

We shall report results on calibration , on physical properties of the sensors, limitations on spatial resolution and pressure sensitivity. We have investigated the classificatory power with respect to material hardness, elasticity and the surface texture. Finally, we outline the open problems and the near future plans.

Integrating Vision and Touch For Robotics Applications
R. Bajcsy
Technical Report MS-CIS-83-08

The aim of this paper is to present an overview of currently available and being developed algorithms for representation and recognition of three-dimensional shape of an object as perceived by visual and/or tactile sensors.

For the visual sensor we assume that we have available stereo cameras or their equivalent. As the tactile sensor, we use an articulated multifingered hand equipped with tactile sensory arrays as the data acquisition device. We shall present available configurations of these devices. Then we shall investigate the sensory processing, in particular what representation schemas should be considered. For example, the observer-centered representation versus object-centered representation, will be discussed. Different features, such as surface properties and volumetric properties and the appropriate extracting algorithms will be examined. Finally, the control strategies that we investigate are primarily hierarchical; that is, analyzing the object first from its coarse characteristics and, only if necessary, examining the finer details. In this context, the strategy will determine how to acquire the data, especially the tactile data.

As examples, first some artificial geometric objects then some real laboratory objects from the blocks world will be analyzed. Finally, examples from medical applications, i.e.; from tomographic images, will be presented.

Logics and Natural Language
Bonnie Lynn Webber
Technical Report MS-CIS-83-18

Logic is that branch of knowledge concerned with truth and inference -- with determining the conditions under which a proposition is true or one proposition may be inferred from others. Such knowledge is essential for communication, since most of our beliefs about the world do not come from direct contact with the world, but rather from what others tell us about it. Hence, it is not surprising that logic underlies a wide range of current research on Natural Language (NL) interaction with machines. However, it is not just first-order logic (FOL) that has been enlisted in this enterprise: other logics have begun to be used as well. This paper discusses three of them: (1) default logic, for computing presuppositions; (2) modal logic, for planning utterances to enlist help; and (3) temporal logic, for offering competent database monitors and correcting certain user misconceptions.

In Response: Next Steps in Natural Language Interaction
T. W. Finin; B. L. Webber
Technical Report MS-CIS-83-27

In the area of man-machine interaction, Natural Language has so far primarily been used to simplify people's access to information. The next step beyond simple data access is the kind of cooperative interactive problem-solving that current expert systems aspire to. But support for problem (which includes helping the user formulate his/her problems) demands more in the way of interaction than just answering requests for the factual information. In the first part of this paper, we illustrate some of these needed capabilities. In the remainder, we discuss two of them in greater detail: (1) recognizing and responding to user misconceptions and (2) getting from users the information needed to help them solve their problems.

Tactile Information Processing
The Bottom Up Approach
Working Paper
Ruzena Bajcsy, Greg Hager
Technical Report MS-CIS-83-38
Grasp Lab 09

A primal sketch for tactile information processing is outlined. It is further argued that from the basic three primitives: hardness, surface normals, and local curvature all other tactile features can be constructed.

A New Model of Computation Based on a Calculus of Type Subsumption
Hassan Ait-Kaci
Technical Report MS-CIS-83-40

I present a design for a programming language based on a calculus of type subsumption. A close analysis of the notion of term in universal algebra and logic shows how the concept of subsumption may be extended to bear more semantic power. I propose a mathematical semantics for a particular language where type structures are first-class objects, and which can be practically implemented. In this language, computation amounts to type checking. I point out possible connections of this model of computation with logic. Finally, I describe further extensions in the language design which can be given well-defined semantics without loss of the basic language philosophy.

TEMPUS: A System for the Design and Simulation of Human Figures in a Task-Oriented Environment
Norman I. Badler, Jonathan Korein, James U. Korein, Gerald M. Radack, Lynne Shapiro, Carolyn
Technical Report MS-CIS-84-03

A system called TEMPUS is outlined which is being developed to simulate graphically the task-oriented activities of several human agents in a three-dimensional environment. TEMPUS is a task simulation facility for the evaluation of complex workstations vis-a-vis the normal and emergency procedures they are intended to support and the types and number of individuals who must carry them out. TEMPUS allows a user to interactively: **Create one or more human figures which are correctly scaled according to a specific population, or which meet certain size constraints.*

**View the human figure in any of several graphical modes: stick figure, line or shaded polygons, or shaded BUBBLEPERSON.*

**Position the figure in any admissible position within joint angle constraints, and with the assistance of a robotics reach positioning algorithm for limbs.*

**Combine the figures with three-dimensional polyhedral objects derived from an existing CAD system.*

**Create shaded graphics images of bodies in such environments.*

**Use all TEMPUS features in an extensible and uniform user-friendly interactive system which does not require any explicit programming knowledge.*

A brief summary of the software engineering of this system in a University environment is included. Other features of TEMPUS and differences between TEMPUS and other available body modeling systems are also discussed.

Consistency in the Face of Partition Failures:
A Survey MS-CIS-84-04
Susan B. Davidson (University of Pennsylvania)
Hector Garcia-Molina (Princeton University)

Recently, several strategies for transaction processing in partitioned distributed database systems have been proposed. We survey these strategies in light of the goal of maintaining reliability. Extensions and combinations are then discussed, and guidelines for the selection of a strategy for a particular application are presented.

A Geometric Investigation of Reach
James Urey Korein (Ph.D. Thesis)
MS-CIS-84-11

This thesis is a geometric investigation of reach. The study is directed toward man-modeling applications, and deals with open kinematic chains of an anthropomorphic nature. These linkages involve redundancy, spherical joints and joint limits. The point of departure is to consider two related problems:

- Reach Problem: Given a simple positional goal, how may the chain be positioned to achieve it?
- Workspace Problem: What is the set of points the chain can reach with its distal end?

These problems have both been studied in the context of robotics, but bear reexamination for the linkages considered here. Particular attention must be paid to the difficulties introduced by the consideration of spherical joints with joint limits and the handling of redundancy.

Several results are given. Two new solutions to the reach problem are developed. One is an analytic solution for the special case of singly redundant chains of the type exemplified by human arms and legs. Second is solution for chains of arbitrary length which makes use of workspace descriptions.

An algorithm is also developed for the approximation of workspaces by polyhedra. Our approach to the workspace computation leads us into an examination of the problem of sweeping polyhedra through space. For the revolute case, we avoid sweeping unnecessary edges by using the *extreme contour* with respect to the axis of rotation.

FOREST
An Expert System for Automatic
Test Equipment
Timothy W. Finin
MS-CIS-84-16

This paper describes FOREST, an expert system for fault isolation and diagnosis in the Automatic Test Equipment (ATE) domain. Current ATE systems can correctly handle 90 to 95 percent of faults, but the residue accounts for a considerable cost in terms of equipment downtime and the human expert's time. FOREST is an attempt to handle this residue of hard problems with current expert systems techniques. In particular, the incorporation of an AI approach allows us to handle two serious problems which the existing decision tree techniques cannot: problems involving multiple faults and problems caused by components or systems which gradually drift out of calibration. FOREST is implemented in PROLOG and has an architecture that combines an object-oriented representation language (FIR), a general inferencing mechanism (PROLOG), and inferencing engine for reasoning with certainty factors (PINE) and an explanation generation system (ELM).

INTERACTIVE CLASSIFICATION
A Technique for the Aquisition and Maintenance of Knowledge Bases
Timothy W. Finin, David Silverman
MS-CIS-84-17

The practical application of frame-based knowledge-based systems, such as in expert systems, requires the maintenance of potentially very large amounts of declarative knowledge stored in their knowledge bases (KBs). As a KB grows in size and complexity, it becomes more difficult to maintain and extend. Even someone who is familiar with the representation and the contents of the existing KB may introduce inconsistencies and errors whenever an addition or modification is made.

This paper describes an approach to this problem based on a tool called an interactive classifier. An interactive classifier uses the contents of the existing KB and knowledge about its representation to assist the person who is maintaining the KB in describing new KB objects. The interactive classifier will identify the appropriate taxonomic location for the newly described object and add it to the KB. The new object is allowed to be a generalization of existing KB objects, enabling the system to learn more about existing objects. The ideas have been tested in a system call KuBIC, for Knowledge Base Interactive Classifier, and are being extended to a more complete knowledge representation language.

Correcting Object-Related Misconceptions: How Should The System Respond?
Kathleen F. McCoy
MS-CIS-84-18

This paper describes a computational method for correcting users' misconceptions concerning the objects modeled by a computer system. The method involves classifying object-related misconceptions according to the knowledge-base feature involved in the incorrect information. For each resulting class sub-types are identified, according to the structure of the knowledge base, which indicate what information may be supporting the misconception and, therefore, what information to include in the response. Such a characterization, along with a model of what the user knows, enables the system to reason in a domain-independent way about how best to correct the user.

A Generalized Object Display Processor Architecture
S.M. Goldwasser
MS-CIS-84-38
GRASP LAB 10

A multiprocessor architecture has been developed which addresses the problem of the display and manipulation of multiple shaded three dimensional objects derived from emperical data on a raster scan CRT. Fully general control of such parameters as position, size, orientation, rotation, tone scale, and shading are accomplished at video rates permitting real-time interaction with the display presentation.

The GODPA architecture is based on a large number of relatively simple processing elements which access their own memory modules without input conflict. Reconstruction algorithms are used which do not require any complex arithmetic or logical high speed operations. This hardware organization is highly modular and expandible and is ideally suited for implementation with VLSI technology.

Angy: A Rule-Based Expert System For Identifying And Isolating Coronary Vessels In Digital Angiograms
S. A. Stansfield
MS-CIS-84-49
GRASP LAB 21

This paper presents work being done in the development of a rule-based expert system for identifying and isolating coronary vessels in digital angiograms. The system is written in OPS5 and LISP and uses low level processors written in C. The system embodies both stages of the vision hierarchy: The low level image processing stage works concurrently with edges (or lines) and regions to segment the input image. Its knowledge is that of segmentation, grouping, and shape analysis. The high level stage then uses its knowledge of cardiac anatomy and physiology to interpret the result and to eliminate those structures not

desired in the output.

The Image Processing Optical Network: Advanced Architecture For Image Processing

Samuel M. Goldwasser
MS-CIS-84-50
GRASP LAB 22

The Image Processing Optical Network (IPON) is an ultra high performance architectural framework being developed to support image acquisition, low and medium level image processing and analysis, image display, and image storage using digital and hybrid technology. IPON assumes the use of the technology of the 1990s and beyond including hybrid optical systems and other novel devices which depart from the strictly 'more gates on semiconductor' philosophy of the past 20 years.

IPON will be an MIMD network utlilizing non-homogeneous functional nodes of a variety of types. It will be dynamically partitionable and reconfigurable using a non-blocking optical interconnection network. IPON will support the use of optical-hybrid technology for key components to provide high bandwidth communications, high capacity buffering, and certain types of high speed processing. User level programming of IPON will be accomplished using the concept of process level dataflow control via an interactive Graphical Image Processing Language.

This paper outlines some initial thoughts on the organization and implementation of IPON.

A Programming System For Distributed Real-Time Applications

Insup Lee
MS-CIS-84-51
GRASP LAB 23

A distributed programming system designed to support the construction and execution of a real-time distributed program is presented. The system is to facilitate the construction of a distributed program from sequential programs written in different programming languages and to simplify the loading and execution of the distributed configuration language. The language is used to write the configuration of a distributed program, which includes resource requirements, process declarations, port connections, real-time constraints, process assignment constraints, and process control statements.

Default Reasoning in Interaction

Aravind Joshi, Bonnie Webber, and Ralph Weischedel
MS-CIS-84-58

Nonmonotonic reasoning is usually studied in the context of a logical system in its own right or as reasoning done by an agent, in which the agent reasons about the world from partial information and hence may draw conclusions unsupported by traditional logic. The main point of departure here is looking at nonmonotonic reasoning in the context of interacting with another agent. This information is partial, in that the other agent neither will not can make everything explicit. Knowing this, the agent may attempt to derive more from the interaction than what has been made explicit, by reasoning by default about what has been made explicit (often by contrast with what he assumes would have been made explicit, were something else the case). Thus there can be rules for default reasoning that are operative in the interactive situation ("interactional defaults") that are not operative with only a single agent.

Preventing False Inferences

Aravind Joshi, Bonnie Webber, and Ralph M. Weischedel
MS-CIS-84-59

In cooperative man-machine interaction, it is taken as necessary that a system truthfully and informatively respond to a user's question. It is not, however, sufficient. In particular, if the system has reason to believe that its planned response might lead the user to draw an inference that it knows to be false, then it must block it by modifying or adding to its response. The problem is that a system neither can nor should explore all conclusions a user might possibly draw: its reasoning must be constrained in some systematic and well motivated way.

Living Up To Expectations:
Computing Expert Responses
Aravind Joshi, Bonnie Webber,
and Ralph Weischedel
MS-CIS-84-60

In cooperative man-machine interaction, it is necessary *but not sufficient* for a system to respond truthfully and informatively to a user's question. In particular, if the system has reason to believe that its planned response might mislead the user, then it must block that conclusion by modifying its response. This paper focusses on identifying and avoiding potentially misleading responses by acknowledging types of "informing behavior" usually expected of an expert. We attempt to give a formal account of several types of assertations that should be included in response to questions concerning the achievement of some goal (in addition to the simple answer), lest the questioner otherwise be misled.

Graph-based Logic
Programming Interpreters
Jean H. Gallier and
Stan Raatz
MS-CIS-84-61

A recent trend in logic programming research has been the development of systems that are not based on the SLD-resolution used in PROLOG. One such example is TABLOG [12], a language employing the Manna-Waldinger deductive tableaux proof system. This paper introduces HORNLOG, a logic programming system which uses a graph based evaluation algorithm.

The method used in HORNLOG is new, and is based on the linear-time algorithm for proving the unsatisfiability of a propositional Horn clause of Dowling and Gallier [6]. It applies to a class of first-order formulae which is a proper superset of the class of clauses handled by PROLOG interpreters. In particular, negative Horn clauses used as assertions (that do not use the negation by failure semantics), and queries consisting of disjunctions of negations of Horn clauses are allowed. Hence, our procedure may return indefinite answers (disjunctions). This method also appears to have an immediate parallel interpretation

A Modal Temporal Logic for Reasoning About Changing Databases with Applications to Natural Language Question Answering

Eric Mays
Aravind Joshi
Bonnie Webber
MS-CIS-85-01

A database which models a changing world must evolve in correspondence to the world. Previous work on natural language question answering systems for databases has largely ignored the issues which arise when the database is viewed as a dynamic (rather than a static) object. We investigate the question answering behaviors that become possible with the ability to represent and reason about the possible evolution of a database. These behaviors include offering to monitor for a possible future state of the database as an indirect response to a query, and directly answering questions about prior and future possibility. We apply a propositional modal temporal logic that captures possibility and temporality to represent and reason about dynamic databases, and present a sound axiomatization and proof and proof procedure.

An Incremental, Strongly-Typed Database Query Language

Rishiyur Sivaswami Nikhil
MS-CIS-85-02

We present an experimental programming system for databases that permits an interactive and applicative style of programming. The system is based on the applicative language FQL, for which we show two versions: a basic version resembling Backus' FP that is compact and easy to implement, and an extended version that resembles ML, and is easier to use. The language is portable in that it can be interfaced easily to existing database systems.

We show a novel implementation technique for FQL that eliminates the need for environments, permits the construction of infinite (or very large) structures, and provides several self-optimizing features. The techniques uses new "machine-based" combinators which offer improvements in performance over the standard S and K combinators.

The language is strongly-typed, supporting polymorphic and higher-order functions, and abstract data types. A type-inferencing algorithm allows us to type-check an expression even in the absence of the type declarations. This type-inference algorithm is also used to resolve the overloading of identifiers.

The Functional Data Model through which databases are viewed meshes cleanly into the type system and the implementation of the language, allowing us to deal with databases without the introduction of any new concepts. The type system also provides a rich "schema-browsing" facility, again within the same framework.

The use of a polymorphic type system in the context of incremental program development is explored. Here a function may be tested (executed) before other functions that it depends on are defined, or modified after other functions depend on it. The type system provides detailed information about the nature and location of type-errors, allowing the minimization of type-checking that must be performed

incrementally.

Explaining Concepts in Expert Systems: The CLEAR System
Robert Rubinoff
MS-CIS-85-06

Existing expert systems provide limited explanatory ability. They can explain the specific reasoning the system uses, but if the user is confused about the concepts and terms the system is using, no help is available. The CLEAR system allows users to ask for explanations of specific concepts. The system generates the explanations by examining the rule base, selecting rules that are relevant to the concept asked about. These rules are then turned into English by various simple translation schemes and presented to the user, providing an explanation of how the concept is used by the system.

Parametric Keyframe Interpolation Incorporating Kinetic Adjustment and Phrasing Control
Scott N. Steketee
Norman I. Badler
MS-CIS-85-07

Parametric keyframing is a popular animation technique where values for parameters which control the position, orientation, size, and shape of modeled objects are determined at key times, then interpolated for smooth animation. Existing interpolation systems for animation are examined and found to lack certain desirable features such as continuity of acceleration or convenient kinetic control. The requirements of interpolation for animation are analyzed in order to determine the characteristics of a satisfactory system. A new interpolation system is developed and implemented which incorporates second-derivative continuity (continuity of acceleration), local control, convenient kinetic control, and joining and phrasing of successive motions. Phrasing control includes the ability to parametrically control the degree and extent of smooth motion flow between separately defined motions.

Local Matching of Surfaces Using Boundary-Centered Radial Decomposition
Gerald Radack
MS-CIS-85-09

The local matching problem on surfaces is: Given a pair of oriented surfaces in 3-space, find subsurfaces that are identical or complementary in shape. A heuristic method will be presented for local matching that is intended for use on complex surfaces (as opposed to such things as cubes and cylinders). The method proceeds as follows:

1. Find a small set of points – called "critical points" – on the two surfaces with the property that if p is a critical point and p matches q, then q is also a critical point. The critical points are taken to be local extrema of curvature, either Gaussian or mean.

2. Construct a rotation invariant representation around each critical point by intersecting the surface with spheres of standard radius centered around the critical point. For each of the resulting curves, compute a "distance contour" function equal to the distance from a point on the curve to the center of gravity of the curve as a function of arc length (normalized so that the domain of the function is the interval $[0,1]$). Call the set of contours for a given critical point a "distance profile."

3. Match distance profiles by computing a "correlation" between corresponding distance

contours.

4. Use maximal compatible subsets of the set of matching profiles to induce a transformation that maps corresponding critical points together, then use a cellular spatial partitioning technique to find all points on each surface that are within a tolerance of the other surface.

This method has been implemented using surfaces represented by polygonal networks as input. Applications of local matching include scene analysis, molecular docking (fitting) and assembly of three dimensional jigsaw puzzles.

Incorporating Measures of Certainty in a Logic Programming System
Stan Raatz and Jean H. Gallier
MS-CIS-85-10

We discuss, in abstract syntax, a class of current production rule languages and their limitations. Traditionally, these languages require that the facts and hypotheses of the problem domain be atomic, finite, and pre-specified before execution. Using the model of logic programming extended with measures of certainty, a new paradigm is discussed that allows relations of certainty between sets, the first-order construction of compound hypotheses as top level plans, and infinite domains of facts and hypotheses which do not necessarily have to be pre-specified before execution. Finally, we discuss recent extensions to the *Hornlog* logic programming system that implement these ideas, give an example, and discuss the motivation behind this research.

Implementation of a Gaussian-Smoothing Gradient-Edge Detector
David Talton
MS-CIS-85-12
GRASP LAB 35

This report describes the theoretical aspects and implementation details of a gaussian-smoothing, gradient-based edge detector. This edge detector is based on Canny's "Finding Edges and Lines in Images" [1]. In this report we discuss the implementation of an algorithm and the results rather than the motivation for the computation.

IPON - Advanced Architectural Framework for Image
D. Smiley, S. M. Goldwasser, I. Lee
MS-CIS-85-13
GRASP LAB 36

The Image Processing Optical Network (IPON) is an ultra high performance architectural framework being developed to support image acquisition, low and medium level image processing and analysis, image display, and image storage using digital and hybrid technology including hybrid optical systems and other novel devices which depart from the strictly 'more gates on semiconductor' philosophy of the past 20 years.

IPON will be an MIMD network utilizing non-homogeneous functional nodes of a variety of types. It will be dynamically partitionable and reconfigurable using a non-blocking optical interconnection network. IPON will support the use of optical-hybrid technology for key components to provide high bandwidth communications, high capacity buffering, and certain types of high speed processing. User level

programming of IPON will be accomplished using the concept of process level dataflow control via an interactive graphical image processing language.

This paper outlines the organization and implementation of IPON in terms of both the hardware and programming environment.

Results in Finding Edges and Corners in Images Using the First Directional Derivative
Eric P. Krotkov
Technical Report MS-CIS-85-14
GRASP LAB 37

This paper presents some results in finding edges and corners in images using the first directional derivative of the image intensity function. The method is to take a *directional* first derivative of the smoothed intensity function, saving the magnitude and direction of the gradient for use in detecting edgels (pixels possibly lying on an edge; local magnitude maximum) and corner point (edgels lying at points of high curvature).

Edgels are found with the Canny operator. The strength of a corner point C is proportional to the product of the gradient magnitude at C and the variance in the gradient directions in a neighborhood about C.

Results are evaluated by comparing subjectively perceived corners with corners detected by the algorithm. The results are excellent for synthetic data (100% localization) and fairly good (90% localization) for noisy real data, with which the number of false alarms rises.

A Computational Logic Approach to Syntax and Semantics
Dale A. Miller and Gopalan Nadathur
MS-CIS-85-17

It is well known that higher-order logics are very expensive, and for this reason have been used to represent many problems in mathematics and theoretical computer science. In the latter domain, higher-order logics are often used to describe the semantics of first-order logics, natural languages, or programs, since the formalization of such semantics needs a recourse to quantification over the domain of functions and sets. In these settings, higher-order logic has generally been limited to a descriptive role. Once the formalization is made little has been made of it computationally, largely because there is abundant evidence that theorem proving in higher-order logics is very difficult. In this paper we shall look at a sublogic of a particular higher-order logic that is derived from Church's Theory of Types, and examine its representational power and its computational tractability. This sublogic can also be described as Horn clauses logic extended with quantifications over function variables and λ-contraction. We shall present a sound and complete theorem prover for this logic, which uses higher-order unification and may be described as an extension of a unification procedure for the typed λ-calculus. There are at least three ways in which this logic is different from the first-order logic that it generalizes. First it possesses function variables which can be instantiated with λ-terms and evaluated through λ-contractions. This provides the logic with a new source of computation. Second, since λ-terms do not have most general

unifiers, the process of finding appropriate unifiers must branch, and hence involves real search. This facet provides a new source of nondeterminism in specifying computations. Finally, this logic can directly encode first-order logic in its term structure and can manipulate such terms in logically meaningful ways. We illustrate this with examples taken from knowledge representation and natural language parsing.

GUIDE: Graphical User Interface Development Environment
Tamar Granor
Norman I. Badler
MS-CIS-85-19

GUIDE is an interactive graphical system for designing and generating graphical user interfaces. It provides flexibility to the system designer while minimizing the amount of code which the designer must write. The GUIDE methodology includes the notions of "tool", "task", and context." GUIDE encourages designers to tailor their systems to individual users by inclusion of "user profile", allowing different control paths based on the user's characteristics. GUIDE also provides a method for invoking application routines with parameters. Parameters may be based on user inputs and are computed at invocation time. Help messages are created along with the objects to which they refer. GUIDE handles the overhead required to display help messages.

TEMPUS: A System for the Design and Simulation of Human Figures in a Task-Oriented Environment
Norman I. Badler, Jonathan Korein, James U. Korein, Gerald M. Radack, Lynne Shapiro Brotman
Technical Report MS-CIS-85-20

A system called TEMPUS is outlined which is being developed to simulate graphically the task-oriented activities of several human agents in a three-dimensional environment. TEMPUS is a task simulation facility for the evaluation of complex workstations vis-a-vis the normal and emergency procedures they are intended to support and the types and number of individuals who must carry them out. TEMPUS allows a user to interactively: *"Create one or more human figures which are correctly scaled according to a specific population, or which meet certain size constraints.*

"View the human figure in any of several graphical modes: stick figure, line or shaded polygons, or shaded BUBBLEPERSON.

"Position the figure in any admissible position within joint angle constraints, and with the assistance of a robotics reach positioning algorithm for limbs.

"Combine the figures with three-dimensional polyhedral objects derived from an existing CAD system.

"Create shaded graphics images of bodies in such environments.

"Use all TEMPUS features in an extensible and uniform user-friendly interactive system which does not require any explicit programming knowledge.

Other features of TEMPUS and differences between TEMPUS and other available body modeling systems are also discussed.

Hierarchical Reasoning: Simulating Complex Processes over Multiple Levels of Abstraction
[A Dissertation Proposal]
Paul A. Fishwick
MS-CIS-84-21

This thesis presents a definition of hierarchical reasoning about processes using different abstraction levels. Most simulation or process reasoning systems permit the monitoring of only a single level of abstraction. Through hierarchical reasoning, the analyst is given much freedom in controlling the flow of actions for a given set of processes over an arbitrary number of levels.

An implementation of the hierarchical reasoning theory called HIRES is also presented. HIRES allows the user to reason in a hierarchical fashion by relating certain facets of the simulation to levels of abstraction specified in terms of actions, objects, reports, and time. High and low level knowledge about interacting, complex processes is integrated into a uniform methodology.

A Distributed Testbed for Active Sensory Processing
I. Lee
S. Goldwasser
MS-CIS-85-22
GRASP LAB 38

A distributed testbed designed to support the development of a multi-sensory (vision and tactile) system for investigations in "active perception" of three dimensional objects is presented. Active perception means being able to not only see and feel objects but also manipulate and probe them. The nucleus of the testbed is a network of heterogeneous computers designed to support low-level real-time control processes as well as high-level knowledge-based systems. The programming environment of the testbed facilitates the construction and execution of a distributed multi-sensory system from sequential programs written in different programming languages.

Fast Surface Rendering Algorithms for 3D Medical Objects
R.A. Reynolds and S.M. Goldwasser
MS-CIS-85-25
GRASP LAB 40

Data captured by automatic 3D digitization equipment such as medical imaging systems are often represented by small volume elements called voxels. The number of voxel faces required to represent a complex object surface can be very large—frequently, several hundred thousand. This paper describes a method of exploiting the simplicity and regularity of the voxel model to render complex surfaces in one or two minutes on a small mini-computer. Although the algorithm imposes certain restrictions on object orientation, it has proven very useful in many practical applications.

The computation time exhibits linear growth with the number of faces making up the object surface, and less than linear growth with the number of pixels making up the image. Because of these unusual and beneficial properties, the algorithm is ideally suited to rapid generation of high resolution images utilizing supersampling, anti-aliasing, shadows and multiple light sources for added quality.

The Design and Analysis of a Stereo Vision Algorithm

David Smitley

MS-CIS-85-27

GRASP LAB 42

Three dimensional information plays a vital role in the study of robotics, scene understanding programs, and human vision systems. Many methods have been developed to extract such information. A brief review of these methods is presented.

Stereo is one such technique for extracting depth information. The stereo problem is reducible to the correspondence problem. The correspondence problem is that of given a feature in one image, finding the corresponding feature in the other. The problem, while easy to state, has proven difficult to solve.

This paper investigates previous attempts at the solution to the correspondence problem and presents a new method, which combines features from the two major classes of techniques used to solve the correspondence problem. The algorithm uses characteristics of edges extracted from the images along with correlation values has been developed in such a manner that the presence of occluded objects in the image, does not effect the performance of the matcher.

The algorithm is tested under a variety of controlled viewing conditions and its performance evaluated. The viewing conditions are controlled by using a scale model of an outdoor scene, and by varying the camera viewing angle, noise and background illumination. Based on matcher performance, active camera control schemes are proposed. Future research directions which include development of vision software performance metrics and active camera control schemes are motivated by the results of this research.

A 3-D Physician's Workstation with Real-Time Performance

S.M.Goldwasser, R.A. Reynolds, T. Bapty, D. Baraff, J. Summers, D. Talton, and E. Walsh

MS-CIS-85-28

GRASP LAB 43

Future medical imaging workstations will incorporate two fundamental capabilities now lacking in most contemporary systems--inherent interaction in three dimensions and true real-time performance. The Voxel Processor architecture represents a design framework for real-time systems with interactive display and manipulation capability for 3-D data obtained from CT, MRI, PET, and ultrasound scanners. Capabilities that are implemented include arbitrary real-time rotation of shaded binary or grey-scale 3-D objects, interactive segmentation based on tissue density, instanteous reslicing of the original data, and the display of dynamically changing objects. This paper reports on the hardware realization of a small scale prototype of the Voxel Processor, together with its integration into a complete physician's workstation with interactive software. Major applications for this system include medical research, clinical diagnosis, surgical planning, and radiation therapy simulations.

Two Sensors Are Better Than One: Example of Integration of Vision and Touch

Peter Allen and Ruzena Bajcsy

MS-CIS-85-29

GRASP LAB 44

While static stereo appears to be a well understood visual process, its practical implementation in certain object domains needs to be carefully examined. We are presenting such an analysis of static stereo computation, based on local (edge and small region) feature matching. We show the inherent errors due to such local matching and argue that other sensory information is necessary for more complete surface reconstruction. We opt to use tactile information to complement the static stereo visual data.

A Distributed Active Sensor Processor System

Samuel Goldwasser and Ruzena Bajcsy

MS-CIS-85-30

GRASP LAB 45

An experimental distributed sensory processing testbed is being developed. The Active Sensory Processor, or ASP machine, is being designed specifically for the investigation of 'active' perception of three dimensional objects moving beyond passive visual shape detection to multimodal probing and manipulation. The term 'active' refers to visual, tactile, force, positioning, acoustic, and ultrasonic sensors which are under direct computer control. The ASP multiprocessor network consists of independent expert systems for the various sensory and control functions.

Computer Architecture for Interactive Display of Segmented Imagery

S.M. Goldwasser

MS-CIS-85-33

GRASP LAB 46

This work addresses aspects of several topics related to the general problems of hardware architecture for high performance interactive display systems for computer processed imagery. The general characteristics important for such systems are outlined with emphasis on multiple format object oriented structures. A special purpose multiprocessor architecture is then described which facilitates the real-time display and interactive manipulation of shaded three dimensional objects or object surfaces on a conventional raster scan CRT. Finally, a summary of some possible alternative technologies for system implementation is presented including a concept proposal for a true three dimensional display system based on hybrid techniques. General comments follow encouraging the active investigation and development of emerging non-traditional technologies for use in architectures for spatially distributed data.

Errors in stereo due to quantization

Franc Solina

MS-CIS-85-34

GRASP LAB 47

Quantization errors in the stereoptic method due to discrete

photoelements in cameras are analyzed and their relations to the distance between the object and the cameras (range), distance among the cameras (baseline) and the focal length of the camera lenses are given.

Back-to-Front Display of Voxel-Based Objects

Gideon Frieder, Dan Gordon, R. Anthony Reynolds

MS-CIS-85-36
GRASP LAB 48

We present a simple technique for displaying 3D represented by a three-dimensional array of volume elements called voxels. Our algorithm traverses the voxels slice-by-slice, working from the back of the scene to the front, projecting each voxel on the screen. No surface detection of z-buffer is needed, and our technique lends itself easily to user manipulation and interaction.

Real-Time Display and Manipulation of 3D Medical Objects: The Voxel Processor Architecture

S.M. Goldwasser and R.A. Reynolds

MS-CIS-85-37
GRASP LAB 49

The fundamental problems associated with the interactive display, manipulation, and editing of three-dimensional (3D) objects obtained from medical imaging systems such as CT, PET, and MRI are addressed. Software, hardware, and firmware techniques for shaded graphics display of medical objects are described and evaluated in terms of flexibility and performance. A special purpose multiprocessor architecture (the Voxel Processor) which has been developed specifically for medical research, clinical diagnosis, and surgical planning is presented. The Voxel processor implements a shaded graphics display system with arbitrary rotation, scaling, translation, slice planes, and tone scale transformations on grey-scale data in true real time. The high-speed image generation algorithms exploit the ability to partition object space and require only simple arithmetic and logical operations. Minimal preprocessing steps are required to prepare object data for the Voxel Processor, and the data are always readily accessible for analysis or editing. The architecture is highly structured and is ideally suited for VLSI implementation.

The Voxel Processor For Display of 3D Medical Objects

S.M. Goldwasser, R.A. Reynolds, L. Ashery, E. Walsh, and A. Wolff

MS-CIS-85-38
GRASP LAB 50

A special purpose multiprocessor computer architecture has been developed for the interactive display and manipulation of three-dimensional medical objects obtained from CT, PET, MRI, and ultrasound based data acquisition system. The Voxel Processor implements a variety of interactive capabilities including arbitrary 3-D rotation, anamorphic scaling, segmentation, and programmable slice planes, on grey scale data in true real-time. A small scale Voxel Processor Prototype (VPP) has been implemented to prove the feasibility of the overall approach to gain experience in the development of interactive techniques which exploit its capabilities. This system provides all of the functionality desired of a 3-D medical workstation but a reduced resolution. The VPP has been used for initial clinical studies and has been extremely well received by physicians, surgeons, and medical researchers.

Fast Methods for 3D Display of Medical Objects

R.A. Reynolds

MS-CIS-85-39
GRASP LAB 51

Modern medical imaging modalities such as computed tomography (CT), magnetic resonance imaging (MRI), and positron emission tomography (PET) commonly collect three-dimensional (3D) data, but present only 2D cross-sectional "slices" for viewing. Some methods for generating true 3D images in space are available (such as holography), but these are not always suitable for this application. Recently, methods have evolved for automatically extracting 3D representations of human organs from a stack of slices, and rendering them on a 2D display using shaded graphics techniques to create the illusion of depth. Applications for this technology include visualization of abnormal growths or bony encroachments, non-invasive planning of major surgery, and radiation therapy simulations.

The available software for shaded graphics display is slow, requiring minutes or hours or preprocessing followed by several minutes to generate each image. Faster techniques are essential to support user interaction with the displayed objects, to provide object motion which is a powerful cue to depth perception, to increase patient throughput and provide faster diagnosis, and to encourage widespread clinical utilization of these tools. Standard computer graphics methods are inefficient in this application because of the large amounts of data involved and the unsophisticated object representations imposed by the data collection devices.

To address these issues we investigate fast display methods utilizing both software and hardware approaches. To limit the preprocessing we consider only object representations based on "voxels" (small volume elements shaped like cubes or rectangular parallelepipeds). To provide the most economic 3D display capability we pay special attention to software which may be implemented on the mini-computers associated with the CT or MRI scanners themselves. We give several new algorithms based on 2D object representations (voxel faces), 3D object representations (solid voxels) and 1D object representations (run-length encoded voxels or line-segments). In each instance we compare and contrast these algorithms in terms of time and space requirements, image quality, and support for interactive facilities. Our fastest software can render large objects in one minute following 5-15 minutes or preprocessing on a small mini-computer. To achieve satisfactory image quality we describe a new shading method (called "gradient shading") which is suitable for this application.

The purpose of this work is three-fold: to develop new algorithms for fast shaded graphics display of medical objects, to determine their strengths and weaknesses, and to evaluate these algorithms in terms of parallel implementations on special purpose hardware. Based on this

work we have devised a multiprocessor architecture capable in principle of displaying and manipulating complex 3D objects in real time. We give a development of this architecture and describe a uniprocessor prototype which has been constructed with off-the-shelf TTL components and achieves update rates of 16 frames per second. Our conclusion is that rapid image generation (one minute per view) is quite feasible with existing mini-computers, and real-time display (30 frames per second) can be achieved with inexpensive technology.

Frictionless Grasping

Jeffrey Trinkle

MS-CIS-85-46

GRASP LAB 52

We present the beginnings of the theory of frictionless grasping which parallels the theory of friction grasping. A general procedure for automatically determining grasp points is outlined, the analogue of which is conspicuously absent from the friction grasping literature. The theory leads naturally to the need for a four-fingered hand with a contact tripod in the palm. Through comparing the contact restraint matrices we show a strong similarity between friction and frictionless grasping. To complete the parallel between the two types of grasping, we discuss how fine motion and manipulation may be performed in the frictionless domain.

The Relationship Between Tree Adjoining Grammars And Head Grammars

Aravind K. Joshi, Vijay-Shanker and David J. Weir

MS-CIS-86-01

LINC LAB 22

Tree Adjoining Grammars (TAG) and Head Grammars (HG) were introduced to capture certain structural properties of natural languages. These formalisms, which were developed independently, appear to be quite different notationally. In this paper we discuss the formal relationship between the class of languages generated by TAG's (TAL) and the class of languages generated by HG's (HL). In particular, we show that HL's are included in TAL's and that TAG's are equivalent to a modification of HG's called Modified Head Grammars (MHG's). The inclusion of MHL in HL, and thus the equivalence of HG's and TAG's, in the most general case remains to be established. We show that this relationship is very close both linguistically and formally, the difference hinging on the status of heads of empty strings and whether one deals with heads directly or with the left and right wrapping positions around the head.

Real-Time Interactive Facilities Associated with a 3-D Medical Workstation

Samuel M. Goldwasser, R. A. Reynolds, D. Talton and E. Walsh

MS-CIS-86-03

GRASP LAB 78

Biomedical workstations of the future will incorporate three-dimensional interactive capabilities which provide real-time response to most common operator requests. Such systems will find application in many areas of medicine including clinical diagnosis, surgical and radiation therapy planning, biomedical research based on functional imaging, and medical education. This paper considers the requirements of these future systems in terms of image quality, performance, and the interactive environment, and examines the relationship of workstation capabilities to specific medical applications. We describe a prototype physician's workstation that we have designed and built to meet many of these requirements (using conventional GRAPHICS technology in conjunction with a custom real-time 3-D processor), and give an account of the remaining issues and challenges that future designers of such systems will have to address.

Analyzing Partition Failure Protocols

Susan B. Davidson

MS-CIS-86-05

Several strategies for transaction processing in partitioned distributed database systems have recently been proposed. However, few of these have been tested, either analytically or by simulation, nor has there been an adequate comparison of the methods. This paper presents a probabilistic model for several of the existing algorithms. Parameters to the model include, among others, the degree of replication of data-items in the database and the state of the network (i.e. the number and size of partitions formed by the failure.

A Fast Algorithm for Testing Unsatisfiability of Ground Horn Clauses with Equations

Jean H. Gallier

MS-CIS-86-06

LINC LAB 38

This paper presents a fast algorithm for testing the unsatisfiability of a set of ground Horn Clauses with or without equational atomic formulae. If the length of the set H of Horn clauses (viewed as the string obtained by concatenating the clauses in H) is n, then the algorithm runs in time $O(n \log(n))$. This algorithm is obtained by generalizing the concept of congruence closure to induced by a set of ground Horn clauses can be obtained by interleaving steps in which an equational congruence closure is computed, and steps in which an implicational type of closure is computed.

A Robust, Distributed Sensor and Actuation, Robot Control System

Richard Paul.Hugh Durrant Whyte and Max Mintz

MS-CIS-86-07

GRASP LAB 57

We propose a robot system consisting of a distributed network of intelligent sensing, action and reasoning agents working in their own local domain of expertise. These agents are linked by a blackboard structure to a coordinator which integrates localized expert knowledge in to a consensus view of the environment. Within this framework we are concerned with integrating uncertain and partial sensor observations and distributing knowledge amongst the agents comprising the system. The resulting controller enhances the parallel solution of tasks, increases robustness of the system and allows new sensing agents to be integrated without affecting the overall system structure. We propose to integrate a number of sensors such as vision, range, touch, force and motion to form a robot capable of performing useful work in the domain of single quantity, small part production.

Consistent Integration and Propagation of Disparate Sensor Observations

Hugh F. Durrant-Whyte

MS-CIS-86-08

GRASP LAB 58

We present a theory and methodology for integrating and propagating geometric sensor observations. The integration policy takes any number of disparate, partial and uncertain observations and optimally combines them into a minimum-risk best estimate consensus view of the state of the environment. These consensus observations are considered to be integrated into a geometric model of the world. A methodology is developed that propagates new observations through this world model, maintaining consistency amongst objects and making maximum use of sensor information.

These policies are applied to a general world model composed of an arbitrary number of objects of any shape, connected by an arbitrary number and configuration of uncertain geometric relations. The sensor models used account for a wide variety of uncertainties and spurious data, and apply to any number of different types of sensor system. The application of these policies and models is demonstrated to be computationally simple.

Range From Focus

Eric P. Krotkov and Jean-Paul Martin

MS-CIS-86-09

GRASP LAB 59

One Method for improving the vision system of a robot is to allow the robot to automatically focus its cameras and to use focus as a depth cue. In this paper, the problem of automatic focusing is reduced, by a theoretical analysis of defocus as a wave aberration which attenuates high spatial-frequencies, to the problem of recovering range from focus is treated using a focus criterion function along with knowledge of the lens parameters to solve the lens law for range. The accuracy of the range measurements is approximately 10% of objects distances between 1 and 2 m.

Hornlog: A Graph Based Interpreter For General Horn Clauses

Jean H. Gallier and Stan Raatz

MS-CIS-86-10

LINC LAB 37

This paper presents HORNLOG, a general Horn clause proof procedure that can be used to interpret logic programs. The system is based on a form of graph-rewriting, and on the linear-time algorithm for testing the unsatisfiability of propositional Horn formulae given by Dowling and Gallier [9]. HORNLOG applies to a class of logic programs which is a proper superset of the class of logic programs handled by PROLOG systems. In particular, negative Horn clauses used as assertions and queries consisting of disjunctions of negations of Horn clauses are allowed. This class of logic programs admits answers which are indefinite, in the sense that an answer can consist of a disjunction of substitutions. The method does not use negation by failure semantics in handling these extensions and appears to have an immediate parallel interpretation.

A Structural Model of The Human Face

Stephen Michael Platt

MS-CIS-86-11

GRAPHICS LAB 11

This dissertation examines the problems of representing and animating complex, highly connected objects. Systems such as these are difficult to describe and animate due to the richness of actions and physical interconnections.

A strategy of partitioning the objects, actions, and application algorithm is proposed which allows complete independence of definition of these three classes. A simple animator has been implemented for a gear-and-axle universe which is capable of detecting inconsistent cyclic systems while correctly animating consistent ones.

An object of proven interest, the human face, is then examined. The face itself consists of a modertately large number of definable regions of expression and a predefined set of performable actions. An action in one of these regions may or may not cause other changes, both in the state of the region and in other adjacent regions. OASIS/F, using the object/action paradigm, was implemented. This representation of the face is capable of animating the face in a realistic manner, preserving the structural properties and idiosyncracies of the face.

Relating Expert System Rule Interactions to Norms of Rule-Based Programming

Stan Raatz and George Drastal

MS-CIS-86-12

LINC LAB 36

We study the effect of adding a rule to a rule-based heuristic classification expert system, in particular, a rule which causes an unforeseen interaction with rules already in the rule set. We show that it is possible for such an interaction to occur between sets of rules, even when no interaction is present between any pair of rules contained in these sets. A method is presented that identifies interactions between sets of rules, and an analysis is given

which relates these interactions to rule-based programming practices which help to maintain the integrity of the knowledge base. We argue that the method is practical given some reasonable assumptions on the knowledge base.

A Common Framework for Edge Detection and Region Growing

Ruzena Bajcsy, Max Mintz and Erica Liebman

MS-CIS-86-13

GRASP LAB 61

The main point of this paper is that if one divides the low level image processing into smoothing, linear filtering (a difference operation) and decision making on whether a point is on a boundary or on a homogeneous surface, then the edge detection and region growing is one and the same process. The last step then is to apply a connectivity test which will lead to either continuous regions or continuous boundaries, depending on which points are being considered.

Rapid Techniques For The Display and Manipulation of 3-D Biomedical Data

Samuel M. Goldwasser

MS-CIS-86-14

GRASP LAB 60

The use of fully interactive 3-D workstations with true real-time performance will become increasingly common as technology matures and economical commercial systems become available. This paper provides a comprehensive introduction to high speed approaches to the display and manipulation of 3-D medical objects obtained from tomographic data acquisition systems such as CT, MR, and PET. A variety of techniques will be outlined including the use of fast software on conventional will be outlined including the use of fast software on conventional minicomputers and frame buffer, hardware assist devices such as array minicomputers and special purpose computer architecture for implementing dedicated high performance systems. While both algorithms and architecture will be addressed, the major theme will center around the utilization of hardware based approaches including parallel processors for the implementation of true real-time systems.

The Pennsylvania Active Camera System

Fil Fuma, Eric Krotkov and John Summers

MS-CIS-86-15

GRASP LAB 62

This technical report summarizes a camera system developed in the GRASP Laboratory by a number of different researchers. This research concerns the design and implementation of an image acquisition system, which will automatically and quickly produce a steady stream of high quality images to be used in computer vision and robotics research. Specifically, the hardware and kinematics of the mechanical linkages, the controllers, and the software support are described.

Natural Language Interactions With Artificial Experts

Tim Finin, Aravind K. Joshi and Bonnie Lynn Webber

MS-CIS-86-16

LINC LAB 08

The aim of this paper is to justify why Natural Language (NL) interaction, of a very rich functionality, is critical to the effective use of Expert Systems and to describe what is needed and what has been done to support such interaction. Interactive functions discussed here include defining terms, paraphrasing, correcting misconceptions, avoiding misconceptions and modifying questions.

Higher-Order Logic Programming

Dale A. Miller and Gopalan Nadathur

MS-CIS-86-17

In this paper we consider the problem of extending Prolog to include predicate and function variables and typed λ-terms. For this purpose, we use a higher-order logic to describe a generalization to first-order Horn clauses. We show that this extension possesses certain desirable computational properties. Specifically, we show that the familiar operational and least fixpoint semantics can be given to these clauses. A language, λ-Prolog that is based on this generalization is then presented, and several examples of its use are provided. We also discuss an interpreter for this language in which new sources of branching and backtracking must be accommodated. An experimental interpreter has been constructed for the language, and all the examples in this paper have been tested using it.

Inheritance and Persistence in Database Programming Languages

Peter Buneman and Malcolm Atkinson

MS-CIS-86-18

In order to represent inheritance, several recent designs for database programming languages have made use of class construct, which can be thought of as a restricted data type with an associated set of instances. Moreover, these classes are persistent: they survive from one program invocation to another. This paper examines whether it is necessary to tie together type, extent

and persistence in order to model inheritance and suggests that they may be separated to provide more general database programming languages. In particular we shall see that it is possible to assign a generic data type to a function that extracts all the objects of a given type in the database so that the class hierarchy can be derived from the type hierarchy. We shall also examine object-level inheritance and its relationship to data types for relational databases. A final section examines ho the various forms of persistence interact with inheritance at both object and type level.

A Domain Theoretic Approach to Higher-Order Relations
Peter Buneman
MS-CIS-86-19

Data Types For Data Base Programming
Peter Buneman
MS-CIS-86-20

Denotational Semantics of Relational Databases
Atsushi Ohori
MS-CIS-86-21

We Present a complete denotational semantics of relational databases. A mathematical model of a semantic domain is constructed and the denotation of each component of the relational model is precisely defined. The general notion of relation schema constraints is defined and sound and complete inference system for general constraints is presented. Functional dependencies, join dependencies and multivalued dependencies are then defined as special cases and their inference rules are deduced. The precise meaning of the lossless join property is also provided.

Focusing
Eric Krotkov
MS-CIS-86-22
GRASP LAB 63

We present solutions to two problems arising in the context of automatically focusing a general-purpose servo-controlled video camera on manually selected targets: (i) how to best determine the focus motor position providing the sharpest focus on an object point at an unknown distance; and (ii) how to compute the distance to a sharply focused object point.

We decompose the first problem into two parts: how to measure the sharpness of focus with a criterion function, and how to optimally locate the mode of the criterion function. After analyzing defocus as an attenuation of high spatial-frequencies and reviewing and experimentally comparing a number of possible criterion functions, we find that a method based on maximizing the magnitude of the intensity gradient proves superior to the others in being unimodal, monotonic about the mode, and robust in the presence of noise. We employ the Fibonacci search technique to optimally locate the mode of the criterion function.

We solve the the second problem by application of the thick lens law. We can compute the distance to objects lying between 1 and 3 m with a precision of 2.5 percent, commensurate to the depth of field of the lens. The precision decreases quadratically with increasing object distance, but this effect is insignificant at the (small) object distances investigated.

The solutions are computed in the time required to digitize and filter 11 images, a total of approximately 15 seconds per point for this implementation.

A Representation for Natural Human Movement
Norman I Badler
MS-CIS-86-23
GRAPHICS LAB 13

The overall goal of our work is human motion understanding. In particular, motion performance, observation, description, and notation impact the form of a motion representation. A representation can be verified by a computer GRAPHICS performance, and thus the effective control of natural-appearing human figure movement is a significant and challenging goal. Characteristics of a computationally realizable human movement representation are discussed, including distinctions between hierarchic levels, kinematics, and dynamics. The qualitative factors of Effort-Shape notation are used to suggest extensions to existing movement representations in directions consistent with known characteristics of human movement and conventional animation. We show how useful and expressive motion qualities may be at least approximated by a combination of kinematics and dynamics computations, with kinetic control modulated by acceleration and decelerations derived from existing interpolation methods. Interactions between motions by phrasing, temporal properties, or relationships may be described and executed within an appropriately detailed model.

Keywords and phrases: Human movement, motion understanding, movement representation, computer animation, simulation, computer GRAPHICS, dynamics.

Real-Time Display and Manipulation of 3-D CT, Pet and NMR Data

Samuel M. Goldwasser, R. A. Reynolds, D. Talton and E. Walsh

MS-CIS-86-24

GRASP LAB 82

A fully interactive physician's workstation which supports the display and manipulation of 3-D medical datasets has been constructed. Based on the Voxel Processor architecture, the system uses special-purpose computer hardware to provide a variety of display modalities in including shaded surface display, multi-planar reconstruction, and 3-D display of dynamically changing objects – all with real-time update rates (15 frames/second). Grey-scale voxel densities are retained throughout the processing so that windowing and thresholding can be accomplished interactively in true real-time. Other real-time features include rotation, scaling, and slice plane control.

This paper describes the 3-D physician's workstation and summarizes the major requirements for future 3-D workstations as they relate to specific medical applications. The general architecture and functional characteristics of advanced 3-D display processors supporting these requirements are presented.

Models of Errors and Mistakes in Machine Perception

Ruzena Bajcsy, Eric Krotkov and Max Mintz

MS-CIS-86-26

GRASP LAB 64

This paper is a first step toward integrating sensor measurements of distance. Its major contributions is to identify and present qualitative models for the errors and mistakes introduced in three particular computer vision distance measurements: range from focus, range from point-based stereo, and range from line-based stereo.

These range measurement techniques are presented as computations, and their dominant sources of error are analyzed qualitatively. We propose to quantify the underlying models for these three range estimation techniques by deriving approximate confidence procedures for the intrinsic parameters and functions which characterize each technique.

Some Aspects Of Default Reasoning In Interactive Discourse

Aravind K. Joshi, Bonnie L. Webber and Ralph M. Weischedel

MS-CIS-86-27

LINC LAB 24

We are concerned with interaction between two agents: one agent is the user and the other agent is a system which plays the role of a helpful cooperative agent. Cooperativeness in interaction has many dimensions. In this chapter, we will be particularly concerned with the role of the cooperative agent in preventing the user coming to false conclusions. In cooperative man-machine interaction, it is taken as necessary that a system respond truthfully to a user's question. It is not, however, sufficient. In particular, if the system has reason to believe that its response might lead the user to draw an inference that it knows to be false, then it must block this inference by modifying or adding to its response. We describe two kinds of false conclusions we are attempting to block by modifying otherwise true response: (1) false conclusions drawn by standard default reasoning, and (2) false conclusions drawn in a task-oriented context on the basis of the user's expectations about the way a cooperative agent will respond. Finally, we discuss constraints limiting the cooperative agent's responsibilities with respect to anticipating the false conclusion that the user may draw from its response.

Some Uses of Higher-Order Logic in Computational Linguistics

Dale A. Miller and Gopalan Nadathur

MS-CIS-86-31

LINC LAB 13

Consideration of the question of meaning in the framework of linguistics often requires and allusion to sets and other higher-order notions. The traditional approach to representing and reasoning about meaning in a computational setting has been to use knowledge representation systems that are either based on first-order logic or that use mechanisms whose formal justifications are to be provided after the fact. In this paper we shall consider the use of a higher-order logic for this task. We first present a version of definite clauses (positive Horn clauses) that is based on this logic. Predicate and function variables may occur in such clauses the terms in the language are the typed λ-terms. Such term structures have a richness that may be exploited in representing meanings. We also describe a higher-order logic programming language, called λ-Prolog, which represents programs as higher-order definite clauses and interprets them using a depth-first interpreter. A virtue of this language is that it is possible to write programs in it that integrate syntactic and semantic analyses into one computational paradigm. This is to be contrasted with the more common practice of using two entirely different computation paradigms, such as DCGs or ATNs for parsing and frames or semantic nets

for semantic processing. We illustrate such and integration in this language by considering a simple example, and we claim that its use makes the task of providing formal justifications for the computations specified much more direct.

Adapting MUMBLE: Experience with Natural Language Generation
Robert Rubinoff
MS-CIS-86-32
LINC LAB 09

This paper describes the construction of a MUMBLE-based [McDonald 83b] tactical component for the TEXT text generation system [McKeown 85]. This new component, which produces fluent English sentences from the sequence of structured message units output from TEXT's strategic component, has produced a 60-fold speed-up in sentence production. Adapting MUMBLE required work on each of the three parts of the MUMBLE framework: the interpreter, the grammar, and the dictionary. It also provided some insight into the generation process and the consequences of MUMBLE's commitment to a deterministic model.

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GRASP LAB 65

Towards a Computational Model of Anaphora in Discourse: Reference to Events and Actions
Ethel Schuster
MS-CIS-86-34
LINC LAB 17

When people talk or write, they refer to things, objects, events, actions, facts and/or states that have been mentioned before. Such context-dependent reference is called **anaphora**. In general, linguists and researchers working in artificial intelligence have looked at the problem of anaphora interpretation as that one of finding the **correct antecedent** for an anaphor-that is, the previous words or phrases to which the anaphor is linked. Lately, people working in the area of anaphora have suggested that in order for anaphors to be interpreted correctly, they must be interpreted by reference to entities evoked by the previous discourse rather than in terms of their antecedents. In this recent work, people have focused on entities of type concrete individual (an x) or set of such individuals (some xs) or generic class of such individuals x's).

This proposal focuses on anaphora interpreted as referring to entities of type event and action. It considers four issues: (i) what aspects of the discourse give evidence of the events and actions the speaker is talking about, (ii) how actions and events are represented in the listener's discourse model, (iii) how to delimit the set of events and actions which correspond to possible choices for a particular anaphor, and (iv) how to obtain the speaker's intended referent to an action or event from that set of possible choices. Anaphoric forms that are used to refer to entities of type action and event include **sentential-it**, **sentential-that** pronominalizations as well as **do it**, **do that**, and **do this** forms. I will concentrate on the four previously mentioned issues along with other mechanisms that will provide us with better tools for the successful interpretation of anaphoric reference in discourse.

GUMS: A General User Modeling System
Tim Finin and David Drager
MS-CIS-86-35
LINC LAB 10

This paper describes a general architecture of a domain independent system for building and maintaining **long term models of individual users** . The user modeling system is intended to provide a well defined set of services for an **application system** which is interacting with various users and has a need to build and maintain models of them. As the application system interacts with a user, it can acquire knowledge of him and pass that knowledge on to the user model maintenance system for incorporation. We describe a prototype general user modeling system (hereafter called GUMS) which we have implemented in Prolog. This system satisfies some of the desirable characteristics we discuss.

Breaking the Primitive Concept Barrier
Robert Kass, Ron Katriel and Tim Finin
MS-CIS-86-36
LINC LAB 11

Building and maintaining a large knowledge base of general information requires a knowledge representation system with precise semantics and an easy knowledge acquisition procedure. Systems such as KL-ONE meet these criteria by using a classifier to install new concepts into a taxonomic structure. These systems use a formal notion of a definition for concepts. Unfortunately, many concepts do not seem to have such precise definitions, and end up represented as primitive concepts. Primitive concepts form a barrier to classification, forcing the user to manually classify a new concept with respect to all primitive concepts in the knowledge base.

We propose an extension to KL-ONE which retains its soundness and greatly reduces the burden on the user during knowledge acquisition. This extension consists of adding an explicit definitional component to concepts and relaxing the strictness of concept definitions themselves. The relaxed definition reduces the number primitive concepts in a knowledge base, enables the classifier to handle concepts that do not have complete definitions and enhances the usefulness of an interactive classifier.

Analyzing Extraposition in A Tree Adjoining Grammar

Anthony S. Kroch and Aravind K. Joshi

MS-CIS-86-37

LINC LAB 12

This paper presents an analysis of the English construction, 'extrapostition from noun phrase' using the formalism of Tree Adjoining Grammar. The alternation discussed relates sentences like 'A review of his book appeared' and 'a review appeared of his book', among other cases.

Protocols for Timed Synchronous Process Communications

Insup Lee and Susan B. Davidson

MS-CIS-86-38

GRASP LAB 66

In distributed real-time systems, communicating processes cannot be delayed for arbitrary amounts of time while waiting for messages. Thus, communication primitives used for real-time programming usually allow the inclusion of a deadline or timeout to limit potential delays due to synchronization. This paper identifies three synchronous communication problems, which differ in the number of participating senders and receivers. For each problem, we present an algorithm and correctness proof. The algorithms are shown to guarantee maximal success in communication and to require the smallest delay intervals during which processes wait for synchronous communication. We also evaluate the number of messages used to reach agreement.

Inferring Domain Plans In Question-Answering

Martha Elizabeth Pollack

MS-CIS-86-40

LINC LAB 14

The importance of plan inference in models of conversation has been widely noted in the computational-linguistics, and its incorporation in question-answering systems has enabled a range of cooperative behaviors. The plan inference process in each of these systems, however, has assumed that the questioner (Q) whose plan is being inferred and the respondent (R) who is drawing the inference have identical beliefs about the actions in the domain. I demonstrate that this assumption is too strong, and often results in failure not only of the plan inference process, but also of the communicative process that plan inference is meant to support. In particular, it precludes the principled generation of appropriate responses to queries that arise from invalid plans. I present a model of plan inference in conversation that distinguishes between the beliefs of the questioner and the beliefs of the respondent. This model rest on an account of plans as mental phenomena: 'having a plan' is analyzed as having a particular configuration of beliefs and intentions. Judgements that a plan is invalid are associated with particular discrepancies between the beliefs that R ascribes to Q, when R believes Q has some particular plan, and the beliefs R herself holds. I define several types of invalidities from which a plan may suffer, relating each to a particular type of belief discrepancy, and show that the types of any invalidities judged to be present in the plan underlying a query can affect the content of a cooperative response. The plan inference model has been implemented in SPIRT – a System for Plan Inference that Reasons about Invalidities Too – which reasons about plans underlying queries in the domain of computer mail.

Research in Artificial Intelligence at the University of Pennsylvania

Brant A. Cheikes

MS-CIS-86-41

LINC LAB 15

This report describes recent and continuing research in Artificial Intelligence and related fields carried on at the University of Pennsylvania. While AI research take place primarily in the Department of Computer and Information Science (in the School of Engineering and Applied Science), many aspects of this research are performed in in collaboration with other engineering departments as well as other schools of the University, such as the College of Arts and Sciences, the School of Medicine, and the Wharton School.

A User Interface Management System Generator

Tamar Ezekiel Granor

MS-CIS-86-42

GRAPHICS LAB 12

Much recent research has been focused on user interfaces. A major advance in interface design is the User

Interface Management System (UIMS), which mediates between the application and the user.

Our research has resulted in a conceptual framework for interaction which permits the design and implementation of a UIMS generator system. This system, called Graphical User Interface Development Environment or GUIDE, allows an interface designer to specify interactively the user interface for an application.

The major issues addressed by this methodology are making interfaces implementable, modifiable and flexible, allowing for user variability, making interfaces consistent and allowing for application diversity within a user community.

Conflict Resolution in Class Conflict Graph Analysis

Susan B. Davidson and Mark M. Winkler
MS-CIS-86-43

Class Conflict Graph Analysis has recently been suggested as a pessimistic-syntactic solution to the partition failure problem. We first present the algorithm and its limitations in the face of failures that split the network into more than two partitions. We then present performance results of three conflict resolution strategies, and discuss their tradeoffs.

Extending SLD-Resolution to Equational Horn Clauses Using E-Unification

Jean H. Gallier and Stan Raatz
MS-CIS-86-44
LINC LAB 39

We study the role of unification modulo a set of equation, or E-unification, in the context of refutation methods for sets of Horn clauses with equality. Two extensions of SLD-resolution based on E-unification are presented, and rigorous completeness results are shown, including an analysis of the ground case for insight into the computational implications. The concept of a congruence closure generalized to sets of ground Horn clauses is central to these completeness results. The first method is general, in that it applies to arbitrary sets of equational Horn clauses, but is not practical as it assumes a precedure which gives an explicit sequence of substitutions for each E-unifier. A second method applies to any set of equational Horn clauses that admits procedures enumerating a complete set of E-unifiers, and appears to be well suited to class of equational logic programs which allows a clean and natural integration of the functional and logic programming paradigms. We compare in detail these methods with related work, and show other methods either explicitly include E-unification or simulate it in some manner.

A Performance Comparison of Optimistic Versus Conservative Conflict Graph Analysis

Susan B. Davidson and Mark M. Winkler
MS-CIS-86-45

Two strategies for processing transaction during partition failures in distributed databases are reviewed: the Optimistic Protocol and Conservative Class Conflict Graph Analysis. Both use graph techniques for detecting and resolving conflicts, although one is 'optimistic', detecting and resolving conflict after the failure is repaired, while the other is 'conservative', detecting and preventing potential conflicts when the failure occurs. A simulation comparing the two approaches with respect to the cost of missed opportunity, the cost of repair, and overhead cost is presented, and test results presented. The Optimistic Protocol generally minimizes missed opportunity, while Conservative Class Conflict Graph Analysis requires less overhead and no repair. The applicability of these approaches to fractured networks involving more than two partitions is also discussed.

An Integration of Resolution and Natural Deduction Theorem Proving

Dale Miller and Amy Felty
MS-CIS-86-47
LINC LAB 16

We present a high-level approach to the integration of such different theorem proving technologies as resolution and natural deduction. This system represents natural deduction proofs as λ-terms and resolution refutations as the types of such λ-terms. These type structures, called **expansion trees**, are essentially formulas in which substitution terms are attached to quantifiers. As such, this approach to proofs and their types extends the formulas-as-type notion found in proof theory. The LCF notion of tactics and tacticals can also be extended to incorporate proofs as typed λ-terms. Such extended tacticals can be used to program different interactive and automatic natural deduction theorem provers. Explicit representation of proofs as typed values within a programming language provides several capabilities not generally found in other theorem proving systems. For example, it is possible to write a tactic which can take the type specified by a resolution refutation and automatically construct a complete natural deduction proof. Such a capability can be of use in the development of user oriented explanation facilities.

A Rudimentary Active Multimodal, Intelligent System For Object Categorization

Sharon A. Stansfield

MS-CIS-86-48

This report presents a design for an intelligent, active, multi-sensory system for generic object recognition. The design incorporates ideas from psychology, artificial intelligence, computer vision, and robotics. The major issues addressed are the development of the tactile perception system, the AI architecture, the integration of multi-modal data, and the sensing strategies for both exploration and reasoning. The representation is frame-based. Objects are represented as collections of features and the relations among them. The architecture is a distributed hierarchy of knowledge-based experts each devoted to some specific perceptual task. At the lowest levels of this hierarchy are the sensors – passive vision and active touch. At the highest levels are the modules responsible for sensing strategies.

A Theory of Modules for Logic Programming

Dale Miller

MS-CIS-86-53

LINC LAB 26

We present a logical language which extends the syntax of positive Horn clauses by permitting implications in goals and in the bodies of clauses. The operational meaning of a goal which is an implication is given by the deduction theorem. That is, a goal D - G is satisfied by a program P if the goal G is satisfied by the larger program P union D. If the formula D is the conjunction of a collection of universally quantified clauses, we interpret the goal D - G as a request to load the code in D prior to attempting G, and then unload that code after G succeeds or fails. This extended use of implication provides a logical explanation of parametric modules, some uses of Prolog's assert predicate, and certain kinds of abstract datatypes. Both a model-theory and proof-theory are presented for this logical language. We show how to build a possible-worlds (Kripke) model for programs by a fixed point construction and show that the operational meaning of implication mentioned above is sound and complete for intuitionistic, but not classical, logic.

An Expert System for Marine Umbrella Liability Insurance Underwriting

Claire Socolovsky Caine

MS-CIS-86-54

LINC LAB 27

This paper describes three versions of an expert system for marine liability insurance underwriting. The first version, built on a PC, was the result of a series of knowledge engineering sessions with an underwriter of an insurance company. The prototype was accurate, but it asked too many marginally relevant questions, without regard to the time and business constraints of the user.

The second version was developed to address this concern. It initially asked only a subset of the relevant questions to arrive at a premium. If the premium was too high, the prototype attempted to reduce it by performing a sensitivity analysis on the results of the first round. This analysis was driven by meta-rules.

The third version was built on a lisp machine using a graphical expert system-building tool. The graphical approach and greater flexibility of the tool provided the user with an overview of the domain and permitted him to have more control over the data.

Any implentation of an expert system for marine liability insurance underwriting should incorporate the lessons learned from each of the three versions of the prototype. In addition, sensitivity analysis and a graphical interface could be useful for expert system domains other than insurance underwriting.

Lanpick – An Expert System for Recommendation of Local Area Network Hardware and Software Products

Gerald P. Stoloff

MS-CIS-86-55

LINC LAB 28

With the rapid emergence and change of local area computer network (LAN) hardware/software technology, managers are currently facing an almost impenetrable morass of products in the marketplace. To decide which hardware and operating software to implement in a given organizational situation requires evaluation of numerous factors, including many whose significance may not be readily apparent.

This thesis identifies many of these factors and presents a model for the decision-making process. In addition, it describes a simple prototype expert system that implements this model and produces recommendations on potentially suitable hardware and operating system software products.

Object Recognition Using Function Based Category Models

Franc Solina

MS-CIS-86-56

GRASP LAB 69

We propose a modeling system for recognition of generic objects. Based on the observation that fulfilling of the same function often results in similar shapes we will consider object categories that are formed around the principle of functionality. The representation consists of a prototypical object represented by prototypical parts and relations between these parts. Parts are modeled by superquadric volumetric primitives which are combined via boolean operations to form objects. Variations between objects within a category are described by allowable changes in structure and shape deformations of prototypical parts. Each prototypical part and relation has a set of associated features that can be recognized in the images. The recognition process proceeds as follows; the input is a pair of stereo reflectance images. The closed contours and sparse 3-D points, the result of low level vision, are analyzed to find domain specific features. The features are used for selecting models from the model data base that are compatible with these features. The selected hypothetical models are then verified on the geometric level by deforming the prototype in allowable way to match the data. We base our design of the modeling system upon the current psychological theories of the human visual perception.

The Role of User Modelling in Intelligent Tutoring System

Robert Kass
MS-CIS-86-58
LINC LAB 41

This paper will explore the role of user modelling in intelligent tutoring systems. Particular emphasis will be placed on two specific aspects of user modelling: the knowledge representation used to contain the model of the user, and the means to acquire that knowledge. In this context we will look at four "classic" intelligent tutoring systems which incorporate user models. These systems are: the BUGGY systems of Brown and Burton. Sleeman's LMS, Clancey's GUIDON and Goldstein's WUSOR. We shall also discuss some later work which affects the nature of user models in intelligent tutoring systems. This will provide a basis for summarizing the state of user modelling in intelligent tutoring systems today. We will conclude that the importance and effectiveness of a user model for an intelligent tutoring system has been demonstrated, but the user models are very hard to build, and very brittle. Future work in this area should focus on two issues: developing the knowledge representation capabilities of the user model to the level of being a psychological model, and developing the knowledge acquisition capabilities of user models to be able to deal with information outside the scope of the domain.

Refutation Methods for Horn Clauses With Equality Based on E-Unification

Jean H. Gallier and Stan Raatz
MS-CIS-86-59
LINC LAB 40

We study the role of unification modulo a set of equations, E-unification, in the context of refutation methods for sets of Horn clauses with equality. Two schema based on E-unification are defined, which, incorporated into a refutation mechanism applying to sets of Horn clauses without equality, yield extensions which admit equality. We present two SLD-resolution methods based on these schema, and rigorous completeness results are shown, including an analysis of the ground case for insight into the computational implications. The first method is general, in that it applies to arbitrary sets of equational Horn clauses, but is not practical as it assumes a procedure which gives an explicit sequence of substitutions for each E-unifier. A second method applies to any set of equational Horn clauses that admits procedures enumerating a complete set of E-unifiers, and appears to be well suited to a class of equational logic programs which allows a clean and natural integration of the functional and logic programming paradigms. We then repeat the process and show extensions to the Hornlog proof procedure.

Japanese Zero Pronominal Bindings: Where Syntax and Discourse Meet

Megumi Kameyama
MS-CIS-86-60
LINC LAB 29

Major grammatical relations such as SUBJECT and OBJECT of a sentence need not be overtly expressed in Japanese. Characterizing the fundamental nature of these 'zero-subjects/objects' is a major task for a grammatical theory. In this paper, I discuss the pattern of their **intra-sentential** anaphoric dependence, in particular, how they may have antecedents in the higher clause within a sentence. I first show major shortcomings of purely syntactic approaches represented by Kuroda (1965) and Huang (1984). I argue then that this pattern is more naturally accounted for by assuming a parallelism with the pattern of **inter-sentential** anaphoric dependence in discourse. This substantiates my present assumption that these unexpressed subjects and objects are **ordinary pronominal elements** (hence the name zero **pronominals**). My account draws on the computational theory of Centering (cf. Sidner 1983; Grosz, Joshi, & Weinstein 1983, 1986) in discourse analysis. The specific dis-

course rule that I propose spells out a default preference hierarchy of the properties to be shared between the antecedent and the zero pronominal. These properties have to do with two grammatical notions: (i) [+/–SUBJECT] (i.e., whether or not SUBJECT) and (ii) [+/–IDENT] (i.e., whether or not the speaker takes the view point of the person referred to in describing the event/situation). SUBJECT and IDENT are, therefore, factors that significantly contribute to local discourse connectedness within and across sentences. This in turn demonstrates a more direct link between sentence grammar and discourse grammar than has been assumed.

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The Role of User Models in Question Answering Systems
Robert Kass and Tim Finin
MS-CIS-86-63
LINC LAB 30

For question answering systems to communicate in a natural manner requires such systems to have knowledge about the system users. This paper explores the role of user models in question answering systems. We begin by characterizing what a user model is and how it can be used. The types of information which a user model may be required to keep about a user are then identified and discussed. The types of information to be kept in a particular user model greatly influence the requirements of the model. User models can be classified along several dimensions which are presented and discussed. Other issues which influence the implementation of the user model will be introduced. A final example of implementing a user model for a personal investment advisor system will be used to illustrate the points presented in the paper.

An Introduction to Tree Adjoining Grammars
Aravind K. Joshi
MS-CIS-86-64
LINC LAB 31

In this paper, we will give a brief introduction to Tree Adjoining Grammars (TAG) and summarize some of the mathematical properties of TAG's. This paper is primarily based on Joshi, Levy, and Takahashi (1975); Joshi (1983, 1985); Vijay-Shanker and Joshi (1985); Joshi, Vijay-Shanker and Weir (1986); and Vijay-Shanker (1986). Linguistic significance of TAG's is discussed in Joshi (1983, 1985), Kroch and Joshi (1985, 1986).

Generation of Natural Language Text Describing a System of Asynchronous, Concurrent Processes
Jugal Kalita and Sunil Shende
MS-CIS-86-66
LINC LAB 33

In this paper, we describe a system which models a set of asynchronous, concurrent processes using a body of explicity sequenced production rules. The system employes an interval-based temporal network for storing historical information. A text planning module traverses this network to search for events which need to be mentioned in a coherent report describing the current status of the system. In addition, the planner also combines similar information for succinct presentation whenever applicable. Finally, we elaborate on how we adapt an available generation module to produce well-structured textual report for our chosen domain.

Integration, Coordination and Control of Multi-Sensor Robot Systems
Hugh F. Durrant-Whyte
MS-CIS-86-67
GRASP LAB 73

This thesis develops a theory and methodology for integrating observations from multiple disparate sensor sources. An architecture for a multi-sensor robot system is proposed, based on the idea of a coordinator guiding a group of expert sensor agents, communicating through a blackboard facility. A description of the robot environment is developed in terms of a topological network of uncertain geometric features. Techniques for manipulating, transforming and comparing these

Information and Multi-Sensor Coordination
Greg Hager and Hugh F. Durrant-Whyte
MS-CIS-86-68
GRASP LAB 74

The control and integration of distributed, multi-sensor perceptual systems is a complex and challenging problem. The observations or opinions of different sensors are often disparate, incomparable and are usually only partial views. Sensor information is inherently uncertain, and in addition the individual sensores may themselves be in error with respect to the system as a whole. The successful operation of a multi-sensor system must account for this

uncertainty and provide for the aggregation of disparate information in an intelligent and robust manner.

We consider the sensors of a multi-sensor system to be members or agents of a team, able to offer opinions and bargain in group decisions. We will analyze the coordination and control of this structure using a theory of team decision making. We present some new analytic results on multi-sensor aggregation and detail a simulation which we use to investigate our ideas. This simulation provides a basis for the analysis of complex agent structures cooperating in the presence of uncertainty. The result of this study are discussed with reference to multi-sensor robot systems, distributed AI and decision making under uncertainty.

A Syntax and Semantics for Deterministic Real-Time Computing

Amy Zwarico and Insup Lee

MS-CIS-86-70

GRASP LAB 75

The timed trace model of deterministic, real-time processes is developed. In this model, real-time processes are represented by their externally observable behaviors. The behavior of a process is represented by a it timed trace, which is an extension of the it trace model defined by Hoare for representing deterministic communicating processes. A syntax for expressing real-time processes is defined which extends Hoare's CSP by adding a time value to the prefix operator and modifying the interpretation of the deterministic choice operator. In this way, the syntax can be used to express both the logical and the temporal properties of real-time processes. A denotational mapping is then defined between the abstract syntax and the it timed trace model. The power of the model is demonstrated by several examples. In these examples, it can be seen that the model represents the execution time of a process, the actual processing time needed to execute a program instruction and the delays caused by interprocess communication.

Toward an Individualized Brain Atlas Elastic Matching

Ruzena Bajcsy and Stane Kovacic

MS-CIS-86-71

GRASP LAB 76

We describe the derivation of an individualized brain atlas which can be used for localization of functional regions in Positron Emission Tomography (PET) scans and/or for quantitative analysis of anatomy in Computed Tomography (CT) scans. First, the preprocessing of CT and PET scans and the construction of an idealized brain atlas is explained followed by the creation of an individualized atlas through global (nonelastic) and local (elastic) matching. The matching is performed in three dimensions rather than on a slice-by-slice basis. In the first step, called global matching, only global transformations such as translation, rotation and scaling are allowed. In the second step, called local or elastic matching, the atlas brain is deformed to match the CT brain of an individual, i.e. the outer edge of the brain atlas is matched to the outer edge of the CT brain and brain atlas ventricles are matched to the CT brain ventricles. Other anatomical structures in the brain atlas are deformed as a side-effect of ventricle and outer edge matching due to the deformations that propagate through the elastic matching process. To deal with larger and smaller deformations different spatial resolution 3D brain images are used.

Finally, some experimental results showing the influence of key parameters on the matching and suggestions for future work are described.

PFL — A Pedagogical Frame Language

Tim Finin

MS-CIS-86-72

LINC LAB 35

This paper describes the simple frame-based representation language PFL. PFL is was written for pedagogical purposes - it does not attempt to be very powerful, expressive or efficient. It is deliberately kept simple, both in its features and in its implementation. PFL is written in Common Lisp and can run on either a Symbolics Lisp Machine or on a VAX in VaxLisp. The complete code for PFL, including a very simple taxonomy, is given in the final section of this paper.

The purpose of PFL (and this paper) is twofold: (1) to describe in the most concrete terms possible (e.g. code) some of the concepts and mechanisms which underly frame-based representation languages and (2) to demonstrate some of the features (with, hopefully, good style) of Common Lisp in the context of a complete, useful program.

Design and Implementation of A Robot Force and Motion Server

Hong Zhang

MS-CIS-86-73

GRASP LAB 77

A robot manipulator is a force and motion sever for a robot. The robot, interpretating sensor information in terms of a world model and a task plan, issues instructions to the manipulator to carry out tasks.

The control of a manipulator first involves motion trajectory generation needed when the manipulator is instructed to move to desired positions. The procedure of generating the trajectory must be flexible and efficient. When the manipulator comes into contract with the environment such as during assembly, it must be able to comply with the geometric constraints presented by the contact in order to perform tasks successfully. The control strategies for motion and compliance are executed in real time by the control computer, which must be powerful enough to carry out the necessary computations. and simple system. A modified hybrid control methods for manipulator compliance is then proposed and implemented. The method overcomes the problems existing in previous approaches such as stiffness control and hybrid control. Finally, a controller architecture is studied to distribute computations into a number of processors to satisfy the computational requirement in a cost-effective manner. The implementation using Intel's single board computers is also discussed. Finally, to demonstrate the system, the motion trajectory and the modified force/motion control scheme are implemented on the controller and a PUMA 260 manipulator controlled from a multi-user VAX/Unix system through an Ethernet interface.

Two Steps Closer to Event Reference

Bonnie Lynn Webber

MS-CIS-86-74

LINC LAB 42

In this paper, I set out to contribute to our understanding of reference to events and situations in two ways: (1) by explaining the part that tense plays in the listener's reconstruction of the events and situations a speaker has chosen to describe and (2) by showing that reference to things evoked clausally can be treated in much the same way as reference to things evoked via noun phrases.

Active Reduction of Uncertainty in Multi-sensor Systems

Greg Hager

MS-CIS-86-76

GRASP LAB 79

If robots are to perform tasks in unconstrained environments, they will have to rely on sensor information to make decisions. In general, sensor information has some uncertainty associated with it. The uncertainty can be conceptually divided into two types: statistical uncertainty due to signal noise, and incompleteness of information due to limitations of sensor scope. Inevitably, the information needed for proper action will be uncertain. In these cases, the robot will need to take action explicitly devoted to reducing uncertainty.

The problem of reducing uncertainty can be studied within the theoretical framework of team decision theory. Team decision theory considers a number of decision makers observing the world via information structures, and taking action dictated by decision rules. Decision rules are evaluated relative to team and individual utility considerations. In this vocabulary, sensors are considered as controllable information structures whose behavior is determined by individual and group utilities. For the problem of reducing uncertainty, these utilities are based on the information expected as the result of taking action.

In general, a robot does not only consider direct sensor observations, but also evaluates and combines that data over time relative to some model of the observed environment. In this proposal, information aggregation is modeled via belief systems as studied in philosophy. Reducing uncertainty corresponds to driving the belief system into one of a set of information states. Within this context, the issues that will be addressed are the specification of utilities in terms of belief states, the organization of a sensor system, and the evaluation of decision rules. These questions will first be studied through theory and simulation, and finally applied to an existing multi-sensor system.

Massive Parallelism in Artificial Intelligence

Lokendra Shastri

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LINC LAB 43

There is a growing interest in highly interconnected networks of very simple processing elements within artificial intelligence circles. These networks are referred to as Connectionist Networks and are playing an increasingly important role in artificial intelligence and cognitive science. This paper attempts to explicate the motivation behind pursuing connectionist networks, and discusses some recent proposals that adopt a connectionist approach to solve problems of visual recognition, knowledge representation and limited inference, and natural language understanding.

A Synthesis Algorithm for Reconfigurable Interconnection Network

Insup Lee and David Smitley

MS-CIS-86-79

GRASP LAB 83

The Performance of a parallel algorithm depends in part on the inter-connection topology of the target parallel system. An interconnection network is called recon-

figurable if its topology can be changed between different algorithm executions. Since communication patterns vary from one parallel algorithm to another, a reconfigurable network can effectively support algorithms with different communication requirements. In this paper, we describe how to generate a network topology that is optimized with respect to the communication patterns of a given task. The algorithm presented takes as input a graph and generates as output a topology that closely matches the given input graph. The topologies generated by our algorithm are analyzed with respect to optimum interconnection topologies for the best, worst, and average cases. Simulation results verify the average case performance prediction and confirm that, on the average, the optimum topologies are generated.

Adding Time to Synchronous Process Communications

I. Lee and Susan B. Davidson

MS-CIS-86-85

In distributed real-time systems, communicating processes cannot be delayed for arbitrary amounts of time while waiting for messages. Thus, communication primitives used for real-time programming usually allow the inclusion of a deadline or timeout to limit potential delays due to synchronization. This paper defines the general problem of timed synchronous communication, and discusses various ways of implementing deadlines. Two particular variations of this problem are then identified which differ in the number of participating senders and receivers, and type of synchronous communication. For each problem, an algorithm is presented and shown to be correct. The algorithms are shown to guarantee maximal success and to require the smallest delay intervals during which processes wait for synchronous communication. We also evaluate the number of messages used to reach agreement.

Stereo Ranging With Verging Cameras: A Practial Calibration Procedure and Error Analysis

Eric Krotkov, Ralf Kories and Knud Henriksen

MS-CIS-86-86

GRASP LAB 86

We present a practical calibration procedure for computing range from stereo disparities with verging cameras, a detailed theoretical model of the expected range errors, and an analysis of their experimentally determined components. To compute stereo disparities we first extract linear image features and then match them using a hypothesize-and-verify method. To compute range we derive the relationship between object distance, vergence angle and disparity, and determine its parameters by a calibration procedure. The expected range errors are due to (i) residuals in the calibrated coefficients, (ii) feature localization errors, and (iii) mistaken matches. Overall, the range of objects lying between 1 and 3 m from the cameras and with a restricted field of view can be computed to 2.5 percent/m, excluding mistaken matches. Including mistaken matches results in performance an order of magnitude worse, leading us to suggest some practical methods to identify them, and a statistical tool to model them.

Modelling the User in Natural Language System

Robert Kass and Tim Finin

MS-CIS-86-87

LINC LAB 45

For intelligent interactive systems to communicate with humans in a natural manner, they must have knowledge about the system users. This paper explores the role of user modelling in such systems. We begin by characterizing what a user model is and how it can be used. The types of information which a user model may be required to keep about a user are then identified and discussed. User models themselves can vary greatly depending on the requirements of the situation and the implementation. We classify the types of user models according to several user modelling dimensions. Since acquiring the knowledge for a user model is a fundamental problem in user modelling, a section is devoted to this topic. Next, the benefits and costs of implementing a user modelling component for a system are weighed in light of several aspects of the interaction requirements which may be imposed by the system. Finally, we summarize the the current state research in user modelling and assess future research topics which must be addressed in order to achieve powerful, general user modelling systems.

Modeling and Animating Human Figures in a CAD Environment

Norman Badler

MS-CIS-86-88

GRAPHICS LAB 14

With the widespread acceptance of three-dimensional modeling techniques, high-speed hardware, and relatively low-cost computation, modeling and animating one or more human figure for the purposes of design assessment, human movement understanding has become feasible outside the animation production house environment. This tutorial will address the state-of-the-art in human figure

geometric modeling, figure positioning, figure animation, and task simulation.

Using Extended Tactics To Do Proof Transformations
Amy P. Felty
MS-CIS-86-89
LINC LAB 46

In this thesis we develop a comprehensive human-oriented theorem proving system that integrates several different proof systems. The main theorem proving environment centers around a natural Gentzen first-order logic system. This allows construction of natural proofs, encourages user involvement in the search for proofs, and facilitates understanding of the resulting proofs. We integrate more abstract automatically generated proofs such as resolution refutations by transforming them to proofs in the Gentzen system. Expansion trees are another proof system used as an intermediate stage in transformations between the abstract and natural systems. They are a compact representation useful for transformations and other computations. We develop a programming language approach to theorem proving based on tactics and tacticals. Our extended tactics provide a method for doing proof transformations, as well as facilitate interactive theorem proving, allowing full integration of interactive and automatic theorem proving. In the system, we explicitly represent proofs in each proof system and view expansion tree proofs as types for Gentzen proof terms. This explicit proof representation allows proofs to be manipulated as meaningful data objects and used in various computations. For example, the proof terms in the natural Gentzen system can be used to obtain natural language explanations of proofs. We foresee several applications for this kind of theorem proving system, such as use as a logic tutor, a tool for doing mathematics, or an enhanced reasoner and explanation facility for existing AI systems.

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Adding Time to the Generalized I/O Construct*

Insup Lee and
S. B. Davidson
MS-CIS-87-01

In distributed real-time systems, communicating process cannot be delayed for arbitrary amounts of time while waiting for messages. Thus, communication primitives used for real-time programming usually allow the inclusion of a deadline or timeout to limit potential delays due to synchronization. This paper discusses the problem of implementing deadlines in general, and the problem of adding timing constraints to the generalized input-output construct of Hoare's CSP in particular. Correctness criteria are identified, and an algorithm is presented and shown to be correct. The solution is also compared with existing solutions to the problem of generalized input-output without timing constraints, *i.e.*, when the deadline is infinite.

What's in a Deep Model? A Characterization of Knowledge Depth in Intelligent Safety Systems

David Klein
and Tim Finin
MS-CIS-87-02
LINC LAB 47

While we can characterize deep and shallow models at a high level of abstraction and contrast their relative merits in a general way, this provides little direction for knowledge engineering. In particular, we lack a definition of exactly what makes a model 'deep', and we lack guidelines as to how deep our models should be for a given application. In this paper we provide a very simple operational definition of 'depth' and use it to analyze the opportunities for varying depth in *intelligent safety systems*. The paper both illustrates a domain-independent mode of analysis for examining levels of deep knowledge, and offers domain-specific guidelines for constructing intelligent safety systems. We draw upon examples of fully implemented systems and some hypothetical ones in the domains of nuclear reactor management, chemical plant control, and management of computer installation operations.

A Model for the Extraction of Image Flow

David J. Heeger
MS-CIS-87-04
GRASP LAB 84

A model is presented, consonant with current views regarding the neurophysiology and psychophysics of motion perception, that combines the outputs of a set of spatiotemporal motion-energy filters to extract optical flow. The output velocity is encoded as the peak in a distribution of velocity-tuned units that behave much like cells of the middle temporal (MT) area of the primate brain. The model appears to deal with the aperture problem as well as the human visual system since it extracts the correct velocity for patterns that have large differences in contrast at different spatial orientations, and it simulates psychophysical data on the coherence of sine-grating plaid patterns.

Visually - Aided Tactile Exploration

Sharon A. Stansfield
MS-CIS-87-06
GRASP LAB 90

In this paper we present a system which utilizes vision and touch for object apprehension. We define apprehension as the determination of the properties of an object and the relationships among these properties. This is in contrast to recognition, which goes a step further in the determination process by attaching a label to the object as a whole. Vision is used to obtain initial information about the object, including position, two dimensional segmentation, and three dimensional edge analysis. This data is then used to guide an active tactile system in its exploration of the object. The visual and tactile data are combined into a spatial polyhedral representation designed to allow further exploration of the object, as well as high level reasoning about the object and its components.

Information Maps for Active Sensor Control

Greg Hager
MS-CIS-87-07
GRASP LAB 91

This paper outlines our current progress in active sensor control. We consider the problem of controlling a nonlinear observation system observing data

implicitly related to parameters of interest. We show how linear estimation theory can be applied to this problem, and develop the notion of an information map showing the information expected from sensor viewpoints. We discuss the robustness of these techniques, and propose a method to enhance their robustness. We expect these maps to be useful in active sensor control.

Types and Persistence in Database Programming Languages

Malcolm P. Atkinson
and O. Peter Buneman
MS-CIS-87-12

The necessity of integrating database and programming language techniques has recently received some long-overdue recognition. Traditionally the interface between a programming language and a database has either been through a set of relatively low-level subroutine calls, or it has required some form of embedding of one language in another. More recently, a number of attempts have been made to construct programming languages with completely integrated database management systems. These languages, which we term *database programming languages*, are the subject of this review.

The design of these languages is still in its infancy; and the purpose of writing such a review is to identify those areas in which further research is required. In particular we shall focus on the problems of providing a uniform type system and providing mechanisms for data to persist. Of particular importance are issues of polymorphism, type inheritance, object identity and the choice of structures to represent sets of similar values. Among our conclusions are that there are areas of programming language research: modules, polymorphism, persistence and inheritance that are needed to achieve the goal of a useful and consistent database programming language. Other areas of equal importance, such as implementation, transaction handling and concurrency, are not examined here in any detail.

Edge Detection for Object Recognition in Aerial Photographs

Helen Lillias Anderson
MS-CIS-87-14
GRASP LAB 96

An important objective in computer vision research is the automatic understanding of aerial photographs of urban and suburban locations. Several systems have been developed to begin to recognize man-made objects in these scenes. A brief review of these systems is presented.

This paper introduces the Pennsylvania LandScan recognition system. It is performing recognition of a scale model of the University of Pennsylvania campus. The LandScan recognition system uses features such as shape and height to identify objects such as sidewalks and buildings.

Also, this work includes extensive study of edge detection for object recognition. Two statistics, edge pixel density and average edge extent, are developed to differentiate between object border edges, texture edges and noise edges. The Quantizer Votes edge detection algorithm is developed to find high intensity, high frequency edges.

Future research directions concerning recognition system development, and edge qualities and statistics are motivated by the results of this research.

The Relevance of Tree Adjoining Grammar to Generation

Aravind K. Joshi
MS-CIS-87-16
LINC LAB 52

Grammatical formalisms can be viewed as neutral with respect to comprehension or generation, or they can be investigated from the point of view of their suitability for comprehension or generation. Tree Adjoining Grammars (TAG) is a formalism that factors recursion and dependencies in a special way, leading to kind of locality and the possibility of incremental generation. We will examine the relevance of these properties from the point of view of sentence generation.

Range Image Interpretation of Mail Pieces with Superquadrics

Franc Solina and
Ruzena Bajcsy
MS-CIS-87-18
GRASP LAB 98

Although mail pieces can be classified by shape into parallelopipeds and cylinders, they do not conform exactly to these perfect geometrical shapes due to rounded edges, distorted corners, and bulging sides. Segmentation and classification of mail pieces hence cannot rely on a limited set of specific models. Variations and deformations of shape can be conveniently expressed when using superquadrics. We show how to recover superquadric models for mail pieces and segment the range image at the same time.

Three Dimensional Object Representation Revisited

Ruzena Bajcsy and
Franc Solina
MS-CIS-87-19
GRASP LAB 99

Categories and shape prototypes are considered for a class of object recognition problems where rigid and detailed object models are not available or do not apply. We propose a modeling system for generic objects to recognize different objects from the same category with only one generic model. We base our design of the modeling system upon the current psychological theories of categorization and human visual perception. The representation consists of a prototype represented by parts and their configuration. Parts are modeled by superquadric volumetric primitives which can be combined via Boolean operations to form objects. Variations between objects within a category are described by changes in structure and shape deformations of prototypical parts. Recovery of deformed superquadric models from sparse 3-D points is developed and some results are shown.

Exploratory Visual Sensing for Determining Spatial Layout with an Agile Stereo Camera System

Eric Paul Krotkov
MS-CIS-87-29
GRASP LAB 101

This dissertation addresses a class of visual perception problems collectively called the spatial layout problem, which requires identifying 'where things are' with respect to the observer, rather than 'what things are.' We propose and implement a constructive solution from the perceptual paradigm of active exploratory sensing - active in the dynamic and adaptive use of sensors, and exploratory in purpose. The sensing device is a unique, agile stereo camera system whose position, orientation and optical parameters are controlled by eleven servomotors driven by a computer. Two exploratory procedures compute the absolute distance (range) to objects in the environment: focus ranging requires first automatically focusing the lens and then solving the Gaussian lens law for the range; stereo ranging with verging cameras requires first identifying corresponding line segments extracted from two images and then triangulating on the object, taking the convergence angle into account. An autonomous cooperative ranging procedure employs focusing and stereo to adaptively verify the results of each other, dramatically improving the reliability of the range measurements (out of 3000 observed points, none are significantly mistaken), and marginally improving their accuracy by maximum likelihood estimation to be approximately 1 percent per meter. A merging procedure combines uncertain range measurements from multiple viewing positions by referring them to a common coordinate frame. A clustering procedure groups the merged measurements into a hierarchical, box-like representation of the spatial layout of the environment. Finally, some connections to the philosophy and psychology of visual perception are explored.

A Compact Representation of Proofs

Dale A. Miller
MS-CIS-87-30
LINC LAB 57

A structure which generalizes formulas by including substitution terms is used to represent proofs in classical logic. These structures, called *expansion trees*, can be most easily understood as describing a tautologous substitution instance of a theorem. They also provide a computationally useful representation of classical proofs as first-class *values*. As values they are compact and can easily be manipulated and

transformed. For example, we present an explicit transformations between expansion tree proofs and cut-free sequential proofs. A theorem prover which represents proofs using expansion trees can use this transformation to present its proofs in more human-readable form. Also a very simple computation on expansion trees can transform them into Craig-style linear reasoning and into interpolants when they exist. We have chosen a sublogic of the Simple Theory of Types for our classical logic because it elegantly represents substitutions at all finite types through the use of the typed λ-calculus. Since all the proof-theoretic results we shall study depend heavily on properties of substitutions, using this logic has allowed us to strengthen and extend prior results: we are able to prove a strengthen form of the first-order interpolation theorem as well as provide a correct description of Skolem functions and the Herbrand Universe. The latter are not straightforward generalization of their first-order definitions.

A Computational Treatment of Locative Relations in Natural Language

Ellen M. Hays
MS-CIS-87-31
LINC LAB 58

This paper discusses a system for talking about objects and spatial relations. The work was done in the context of a project called Landscan, for Language-Driven Scene Analyser. The system takes questions in natural language about a partially analysed image of a scene, extends the analysis of the scene as necessary, and responds with information about the objects it contains. Image processing and reasoning about the scene are guided by the input query. Landscan comprises (1) a vision system, which is responsible for image processing and object recognition, (2) a language processor, responsible for understanding the input queries, and (3) a reasoning agent, to determine what is already known or knowable about the subject of the query, to formulate requests for data to the vision system as necessary, and to compile those data into meaningful answers.

This report is concerned with the last two. Since most queries in this context concern objects and their spatial relations, it describes a computational treatment of Herskovits' work on locative expressions, and evaluates the usefulness of Herskovits' approach for this system. It also proposes a general design for the reasoner/interface, outlines the protocols required for the language and vision systems to interact with it, and points out aspects of the project needing particular attention. The very ambitious scope of the Landscan project has naturally made it difficult to do more than point the way to further exploration of many issues.

Characterizing Structural Descriptions Produced by Various Grammatical Formalisms

K. Vijay-Shanker,
David J. Weir and
Aravind K. Joshi
MS-CIS-87-35
LINC LAB 62

We consider the structural descriptions produced by various grammatical formalisms in terms of the complexity of the paths and the relationship between paths in the sets of structural descriptions that each system can generate. In considering the relationship between formalisms, we show that it is useful to abstract away from the details of the formalism, and examine the nature of their derivation process as reflected by properties of their *derivation trees*. We find that several of the formalisms considered can be seen as being closely related since they have derivation tree sets with the same structure as those produced by Context-Free Grammars. On the basis of this observation, we describe a class of formalisms which we call Linear Context-Free Rewriting Systems, and show they are recognizable in polynomial time and generate only semilinear languages.

The Utilization of Processors Interconnected with a Reconfigurable Network

David Smitley
MS-CIS-87-37
GRASP LAB 104

This dissertation addresses the problem of generating parallel processor interconnection topologies that are optimized with respect to the communication patterns of a parallel task graph. We first describe a class of interconnection networks called r-reconfigurable networks. This class of networks can

be configured into any topology in which the number of communication links connected to a processor is less than or equal to some constant r. The dissertation presents several ways of implementing r-reconfigurable networks. Each implementation is characterized by a relatively slow reconfiguration time. Thus, the network topology is fixed before task execution and remains fixed throughout execution.

Given a r-reconfigurable network, the problem is that of synthesizing a network topology that matches the communication requirements of a parallel program. This dissertation shows that this problem is NP-complete. Therefore, heuristic algorithms are developed and used to generate sub-optimum topologies. These topologies are analyzed with respect to a lower bound on optimum interconnection topologies to determine the best, worst, and average case behavior. In addition, a model of the dynamic behavior of the network is developed and used to determine the decrease in average message delay that synthesis can provide. The results show that by using the algorithms given in the dissertation, average message delay in parallel processing systems can be reduced by up to a factor of two over the conventional approach of mapping a task graph onto a fixed processor graph. This implies that r-reconfigurable networks in tandem with the synthesis algorithms given in this dissertation can be used to improve the throughput of parallel processing systems.

On The Progression From Context-Free To Tree Adjoining Languages

K. Vijay-Shanker, David J. Weir and Aravind K. Joshi
MS-CIS-87-38
LINC LAB 63

Minimal Consequence in Sentential Logic

Mary-Angela Papalaskari and Scott Weinstein
MS-CIS-87-43
LINC LAB 66

In this paper we define minimal consequence in sentential logic and present a number of results of a model-theoretic and recursion-theoretic character about this newly introduced non-monotonic consequence relation. We show that the minimal consequence relation is not compact and is Π_2^0 and not Σ_2^0. We also connect this relation to questions about the completion of theories by "negation as failure." We give a complete characterization of the class of theories in sentential logic which can be consistently completed by "negation as failure" using the newly introduced notion of a subconditional theory. We show that the class of theories consistently completable by negation as failure is Π_2^0 and not Σ_2^0.

An Aid to Database Design: An Inductive Inference Approach

Sitaramaswamy Venkata Lanka
MS-CIS-87-47
LINC LAB 68

The conventional approach to the design of databases has the drawback that to specify a database schema, it requires the user to have knowledge about both the domain and the data model. That is, the onus of encoding the domain information in terms of concepts foreign to the domain falls on the user. The goal of this research is to free the user of such burdens. We propose a system that designs a database based on its functional requirements. The user need only provide information on how the database is expected to be used, and the system infers a schema from this. Furthermore, the information is expressed in a language which is independent of the underlying data model.

The above problem has been cast as a inductive inference problem. The input is in the form of Natural Language (English) queries and a conceptual database schema is inferred from this. The crux of the inference mechanism is that the hypotheses are synthesized compositionally and this is described in terms of Knuth's attribute grammars.

In certain situations the inference mechanism has the potential to synthesize false hypothesis. We have advanced a method to detect these potentially false hypotheses, and refine them to obtain acceptable hypotheses.

A prototype of such a system has been implemented

on the symbolics Lisp machine.

A Higher-Order Logic as the Basis for Logic Programming

Gopalan Nadathur
MS-CIS-87-48
LINC LAB 69

The objective of this thesis is to provide a formal basis for higher-order features in the paradigm of logic programming. Towards this end, a non-extensional form of higher-order logic that is based on Church's simple theory of types is used to provide a generalization to the definite clauses of first-order logic. Specifically, a class of formulas that are called higher- order definite sentences is described. These formulas extend definite clauses by replacing first-order terms by the terms of a typed λ-calculus and by providing for quantification over predicate and function variables. It is shown that these formulas, together with the notion of a proof in the higher-order logic, provide an abstract description of computation that is akin to the one in the first-order case. While the construction of a proof in a higher-order logic is often complicated by the task of finding appropriate substitutions for predicate variables, it is shown that the necessary substitutions for predicate variables can be tightly constrained in the context of higher-order definite sentences. This observation enables the description of a complete theorem-proving procedure for these formulas. The procedure constructs proofs essentially by interweaving higher-order unification with backchaining on implication, and constitutes a generalization, to the higher-order context, of the well-known SLD-resolution procedure for definite clauses. The results of these investigations are used to describe a logic programming language called λProlog. This language contains all the features of a language such as Prolog, and, in addition, possesses certain higher-order features. The nature of these additional features is illustrated, and it is shown how the use of the terms of a (typed) λ-calculus as data structures provides a source of richness to the logic programming paradigm.

Word-Order Variation In Natural Language Generation

Aravind K. Joshi
MS-CIS-87-49
LINC LAB 70

In natural language generation the grammatical component has to be systematically interfaced to the other components of the system, for example, the planning component. Grammatical formalisms can be studied with respect to their suitability for generation. The tree adjoining grammar (TAG) formalism has been previously studied in terms of incremental generation. In this paper, the TAG formalism has been investigated from the point of view of its ability to handle word-order variation in the context of generation. Word-order cannot be treated as a last minute adjustment of a structure; this position is not satisfactory cognitively or computationally. The grammatical framework has to be able to deal with the word-order phenomena in a way such that it can be systematically interfaced to the other components of the generation system.

An Optimal Linear-Time Parallel Parser for Tree Adjoining Languages

Michael A. Palis,
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LINC LAB 71

An optimal parallel recognition/parsing algorithm is presented for languages generated by tree adjoining grammars (TAG's), a grammatical system for natural language. TAG's are strictly more powerful than context-free grammars (CFG's), e.g., they can generate $\{a^n b^n c^n \mid n \geq 0\}$ which is not context-free. However, serial parsing of TAG's is also slower, having time complexity $O(n^6)$ for inputs of length n (as opposed to $O(n^3)$ for CFG's). The parallel algorithm achieves optimal speed-up: it runs in linear time on a 5-dimensional array of n^5 processors. Moreover, the processors are finite-state; i.e., their function and size depends only on the underlying grammar and not on the length of the input.

Learning Algorithms for Connectionist Networks: Applied Gradient Methods of Nonlinear Optimization

Raymond L. Watrous
MS-CIS-87-51
LINC LAB 72

The problem of learning using connectionist networks, in which network connection strengths are modified systematically so that the response of the

network increasingly approximates the desired response can be structured as an optimization problem. The widely used back propagation method of connectionist learning is set in the context of nonlinear optimization. In this framework, the issues of stability, convergence and parallelism are considered.

The contribution of the momentum term [19,18] to more rapid convergence is interpreted relative to the geometry of the weight space. It is shown that in plateau regions of relatively constant gradient, the momentum term acts to increase the step size by a factor of $1/(1-\mu)$, where μ is the momentum term. In valley regions with steep sides, the momentum constant acts to focus the search direction toward the local minimum by averaging oscillations in the gradient.

The Davidon-Fletcher-Powell and Broyden-Fletcher-Goldfarb-Shanno methods are considered in light of computational complexity (time and space), convergence properties, and suitability to parallel machines. These algorithms approximate the second derivative of the objective function iteratively. This additional information about the shape of the weight space allows for dramatically faster convergence. The performance of these algorithms is compared with the steepest descent and back propagation algorithms for several sample connectionist problems, including exclusive-OR and a multiplexor problem.

It is concluded that for moderate sized problems the use of higher-order techniques is mandated by their excellent convergence properties.

Redundancy: An Approach to the Efficient Implementation of Semantic Integrity Assertions

Magdi N. Kamel and
Susan B. Davidson
MS-CIS-87-53

Semantic integrity assertins more accurately model the real world by defining consistent database states; however they are expensive to enforce since their checking may require numberous database accesses. In this paper, we propose an efficient method for enforcing integrity assertions expressed in a relational calculus-like language with an arbitrary number of quantifiers and a general logical structure. The method is based on storing carefully chosen clustered redundant data whose benefit for testing the assertions exceeds the cost of updating them.

Representing Generic Objects For Exploration and Recognition

Sharon A. Stansfield
MS-CIS-87-61
GRASP LAB 112

Generic objects are familiar to all of us -- as a matter of fact, we spend our lives surrounded by them. We speak, for instance, of cups and shirts and hammers, usually reverting to more specific descriptions (such as the blue porcelain teacup with the fluted rim) only when it is necessary to distinguish between two objects within the same basic category. It would seem reasonable, then, to give robots this same capability of reasoning in terms of classes of objects. In this paper we present a knowledge representation mechanism for reasoning about generic objects. The task is active tactile exploration for object identification. Objects are first imaged visually and are then explored haptically. Our object representation is feature-based, with geometric/spatial information coming from a model which we call the *spatial polyhedron*. If there is only one hypothesis about the identity of the object, the system generates verification strategies. If there is more than one hypothesis, then the system uses feature-based reasoning to generate strategies for distinguishing among the various possibilities.

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MS-CIS-87-44
GRASP LAB 107

The Mechanics and Planning of Enveloping Grasp

Jeffrey Coates Trinkle
MS-CIS-87-46
GRASP LAB 108

An enveloping grasp is one for which the fingers surround the object and hold it securely against the palm. It is the kind of grasp that we use to hold the steering wheel of our car or to hold a wet ice cube. In the case of the ice cube and other slippery objects, we must use an enveloping grasp, because friction forces are small.

In this dissertation we are particularly interested in achieving an enveloping grasp of an object by manipulating it away from its supporting surface with an articulated hand. To solve the problem, we make several extensions to the firmly established kinematic equations of grasping and develop a linear program to predict the instantaneous motion of a slippery object during its manipulation.

We define the liftability regions for any two-dimensional object and develop a graphical method to determine them. The liftability regions are used to select the initial grasp of the object. Then lift planning strategies determine how the manipulate the object from its initial position into an enveloping grasp in the hand. After achieving envelopment, the grasp is adjusted, maintaining its enveloping character while optimizing an appropriate objective function. These three planning steps, initial grasp selection, lift planning, and grip adjustment are used to determine a grasping plan.

The motion linear program is used as the basis of a simulator which solves the equations of motion of the manipulated object. Given a grasp plan, the simulator is used to verify its validity.

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with backchaining on implication, and constitutes a generalization, to the higher-order context, of the well-known SLD-resolution procedure for definite clauses. The results of these investigations are used to describe a logic programming language called λProlog. This language contains all the features of a language such as Prolog, and, in addition, possesses certain higher-order features. The nature of these additional features is illustrated, and it is shown how the use of the terms of a (typed) λ-calculus as data structures provides a source of richness to the logic programming paradigm.

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It is concluded that for moderate sized problems the use of higher-order techniques is mandated by their excellent convergence properties.

Line-Based Stereo Matching

Knud Henriksen
MS-CIS-87-52
GRASP LAB 109

Perception of depth is a central problem in machine vision. Steropisis is a method for recovering the 3-dimensional structure of a scene from a pair of images acquired from different positions. Stereo is an attractive technique for depth perception because it is passive, fast and accurate, which makes it useful in almost any environment.

This report describes the development of a feature based stereo matcher. The features used for matching are straight line segments extracted from a pair of images. The report describes the development of algorithms for filtering the images, extracting straight line segments from the images, and for matching the extracted line segments. Also, the report presents some experimental results obtained by running the developed stereo matcher on real images.

Redundancy: An Approach to the Efficient Implementation of Semantic Integrity Assertions

Magdi N. Kamel and
Susan B. Davidson
MS-CIS-87-53

Semantic integrity assertins more accurately model the real world by defining consistent database states; however they are expensive to enforce since their checking may require numberous database accesses. In this paper, we propose an efficient method for enforcing integrity assertions expressed in a relational calculus-like language with an arbitrary number of quantifiers and a general logical structure. The method is based on storing carefully chosen clustered redundant data whose benefit for testing the assertions exceeds the cost of updating them.

Motivating Time As a First Class Entity

Insup Lee,
Susan Davidson
and Victor Wolfe
MS-CIS-87-54
GRASP LAB 115

In hard real-time applications, programs must not only be functionally correct but must also meet timing constraints. Unfortunately, little work has been done to allow a high level incorporation of timing constraints into real-time programs. Instead the programmer is required to ensure system timing through a complicated synchronization process or through low level programming, making it difficult to create and modify programs. In this report, we outline six features that must be integrated into a high level language and underlying support system in order to promote time to a first class position in real-time programming systems: expressibility of time, real-time communication, enforcement of timing constraints, fault tolerance to violations of constraints, ensuring distributed system state consistency in the time domain, and static timing verification. We then describe an integrated approach to provide these features using a high level distributed programming language and system tools such as compilers, operating systems, and timing analyzers to enforce and verify timing constraints, and discuss implementation considerations.

A Modular Feedback System for Image Segmentation

Helen L. Anderson,
Ruzena Bajcsy
and Max Mintz
MS-CIS-87-56
GRASP LAB 110

A new paradigm for image segmentation is developed based on modular feedback. This paradigm unifies the concepts of edge detection and region growing into a context independent framework. The feedback process is driven by expectations about segmentation scale, including the number of regions, the range of region sizes, and the equivalent aspect ratios of the regions. Feedback rules are used to set all parameters, based on bottom-up analysis. These results apply to all domains in which region borders have higher gradient values than region interiors. This paradigm is applied to images from different domains, including aerial photographs, an indoor scene and a slice of a human brain.

Explaining and Refining Decision-Theroretic Choices

Dave A. Klein
MS-CIS-87-57
LINC LAB 74

As the need to make complex choices among competing alternative actions is ubiquitous, the reasoning machinery of many intelligent systems will include and explicit model for making choices. Decision analysis is particularly useful for modelling such choices, and its potential use in intelligent systems motivates the construction of facilities for automatically explaining decision-theoretic choices and for helping users to incrementally refine the knowledge underlying them. The proposed thesis addresses the problem of providing such facilities. Specifically, we propose the construction of a domain-independent facility called UTIL, for explaining and refining a restricted but widely applicable decision-theoretic model called the *additive multiattrobite value model*. In this proposal we motivate the task, address the related issues, and present preliminary solutions in the context of examples from the domain of intelligent process control.

On the Relationship Between User Models and Discourse Models

Tim Finin
and Robert Kass
MS-CIS-87-58
LINC LAB 75

This note describes our views on the relationship between *discourse models* (DM) and *user models* (UM) in a natural language processing system. Although the two general notions are closely related, our position is that each has some unique aspects. We will address three particular issues: (1) what information belongs in the DM proper, the UM proper and their "intersection", (2) how could one acquire the knowledge that goes into a DM and a UM and (3) how is knowledge transferred from the UM to the DM, and vice versa.

An Architecture for Multi-Functional Natural Language Systems

Brant A. Cheikes
MS-CIS-87-60
LINC LAB 76

Given enough motivation, people can, with little apparent effort, provide useful, appropriately phrased responses to questions. Doing so involves identifying the information to be conveyed and fitting the style of its presentation to the context. Many factors are considered in this process, including the hearer's knowledge state as well as his beliefs about the speaker's knowledge state, plans, and goals. Responses often consist of several parts, each part communicating information the respondent *believes* to be needed by or useful to the questioner, based on the former's analysis of the situation. Distinct patterns of reasoning seem to underlie each part of a response, and it appears reasonable to hypothesize that for each piece of a response a particular processing strategy can be identified that produces it.

One of many aims of natural language processing research is the development of effective *question-answering systems*: computer systems that can interact with people and answer questions with a human or near-human level of language competence. For such an effort to be successful, mechanisms need to be developed that produce language behavior similar to that of people. To this end, researchers have identified several types of response behavior, in many cases suggesting computational methods to emulate those behaviors. Unfortunately, the development of techniques for combining several different kinds of behavior into a coherent response is a research problem that has for the most part been neglected.

In this thesis, I define the problem of building what I call **integrated multi-behavioral interactive systems**, present and defend what I believe are crucial properties any such system must possess, then describe an architecture that satisfies the design criteria.

Representing Generic Objects For Exploration and Recognition

Sharon A. Stansfield
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Generic objects are familiar to all of us -- as a matter of fact, we spend our lives surrounded by them. We speak, for instance, of cups and shirts and hammers, usually reverting to more specific descriptions (such as the blue porcelain teacup with the fluted rim) only when it is necessary to distinguish between two objects within the same basic category. It would seem reasonable, then, to give robots this same capability of reasoning in terms of classes of objects. In this paper we present a knowledge representation mechanism for reasoning about generic objects. The task is active tactile exploration for object identification. Objects are first imaged visually and are then explored haptically. Our object representation is feature-based, with geometric/spatial information coming from a model which we call the *spatial polyhedron*. If there is only one hypothesis about the identity of the object, the system generates verification strategies. If there is more than one hypothesis, then the system uses feature-based reasoning to generate strategies for distinguishing among the various possibilities.

BBC: A Blackboard Generating System

Joshua Levy
and Tim Finin
MS-CIS-87-62
LINC LAB 77

This note describes a blackboard system generator, Blackboard Builder in C (BBC). This generator is unique because it is a compiler producing the black board system as a separate program, and because the resulting black board system is implemented in C. This short note motivates the migration of blackboard systems from LISP to C, describes the general architecture we have designed, and discusses our current implementation.

Abductive Reasoning in Multiple Fault Diagnosis

Gary Morris
and Tim Finin
MS-CIS-87-63
LINC LAB 78

Abductive reasoning involves generating an explanation for a given set of observations about the world. Abduction provides a good reasoning framework for many AI problems, including diagnosis, plan recognition and learning. This paper focuses on

the use of abductive reasoning in diagnostic systems in which there may be more than one underlying cause for the observed symptoms. In exploring this topic, we will review and compare several different approaches, including Binary Choice Bayesian, Sequential Bayesian, Causal Model Based Abduction, Parsimonious Set Covering, and the use of First Order Logic. Throughout the paper we will use a simple diagnostic problem involving automotive troubleshooting.

Toward Reasoning Methods for Automatic Mechanical Repair

Pearl Pu
MS-CIS-87-64
GRAPHICS LAB 16

A knowledge representation scheme, QUORUM (QUalitative reasoning Of Repair and Understanding of Mechanisms), has been constructed to apply qualitative techniques to the mechanical domain, which is an area that has been neglected in the qualitative reasoning field. In addition, QUORUM aims at providing foundations for building a repair expert system.

The problem in constructing such a representation is the difficulty of recognizing a feasible ontology with which we can express the behavior of mechanical devices and, more importantly, faulty behaviors of a device and their causes. Unlike most other approaches, our ontology employs the notion of force and energy transfer and motion propagation. We discuss how the overall behavior of a device can be derived from knowledge of the structure and the topology of the device, and how faulty behaviors can be predicted based on information about the perturbation of some of the original conditions of the device. Necessary predicates and functions are constructed to express the physical properties of a wide variety of basic and complex mechanisms, and the connection relationships among the parts of mechanisms. Several examples analyzed with QUORUM include a pair of gears, a spring-driven ratchet mechanism, and a pendulum clock. An algorithm for the propagation of force, motion, and causality is proposed and examined.

Semi-Materialization: A Technique for Optimizing Frequently Executed General Queries

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The performance of frequently executed queries can be greatly improved by keeping the result of these queries materialized. However, the cost of maintaining materialized queries during routine update is often high. This is especially so in the case of queries with universal quantifiers; these may require a complete re-evaluation of the query to maintain its stored materialization. In this paper, we propose an efficient method for evaluating frequently executed queries with an arbitrary number of quantifiers and a general logical structure. The method is based on storing carefully chosen clustered redundant subsets of data that represent an intermediate state of query evaluation. These sets are chosen to permit the efficient evaluation of the query, but are easy to maintain.

Querying Independent Databases

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We propose a simple method of providing integrated access to a collection of pre-existing, heterogeneous databases connected over a computer network. The user is presented with a collection of unmerged local schemas that have been translated into the relational model. He then expresses his query as selections and projections on some abstract concept. Although the abstract concept may not be explicitly represented in any of the underlying local schemas, the user must be able to relate it to relations in the local schemas in terms of "*is-a*" relationships. The system then determines how to present some approximation of the desired information to the user.

Relating Logic Programs and Attribute Grammars

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LINC LAB 79

In this paper we study the relationship between Attribute Grammars and Logic Programs, concentrating in transforming Logic Programs into Attribute Grammars. This has applications in compilation techniques for Logic Programs. It does not seem possible to transform arbitrary Logic Programs into Attribute Grammars, basically because the same logic variables can sometimes be used as input and sometimes as output. We introduce the notion of an Abstract Attribute Grammar, which is similar to that of an Attribute Grammar with the exception that attributes are not classified into inherited and synthesized, and that the semantic equations are replaced by restriction sets. These sets represent a restriction on the values of attribute occurrences namely, all elements within each set have to be equal. We give an effective translation schema which produces an equivalent Abstract Attribute Grammar for a given Logic Program. We provide a formal proof of this equivalence. We then proceed to classify a class of

Abstract Attribute Grammars that can be transformed into Attribute Grammars, and show how to achieve this transformation. By composing both transformations one can transform certain Logic Programs into Abstract Attribute Grammars and then into Attribute Grammars.

A Compact Multiresolution Representation: The Wavelet Model

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GRASP LAB 113

It is now well admitted in the computer vision literature that a multiresolution decomposition provides a useful image representation for vision algorithms. In this paper we show that the *wavelet theory* recently developed by the mathematician Y. Meyer enables us to build a compact multiresolution representation for computer vision applications. In computer vision we generally do not want to analyze an images at several resolution levels because the information is redundant. After processing the signal at a resolution r_0, it is more efficient to analyze only the *additional details* which are available at a higher resolution r_1. This difference of information can be computed by decomposing the signal on a wavelet orthonormal basis and it can be efficiently calculated with a pyramid transform using quadrature mirror filters. This will lead us to a complete representation of the signal called a *wavelet representation*, which provides a coarse approximation of the signal (resolution r_0) plus the additional details for a sequence of resolutions $(r_j)_{0 \leq j \leq N}$ $(r_j < r_{j+1})$. The original signal can easily be reconstructed from this representation. We will give a procedure to quantize optimally a wavelet representation by minimizing the energy of the quantization noise on the reconstructed image. This allows us to compress the amount of data representing the original image by a factor 35 with no perceptual degradation on the reconstructed image. Such a decomposition is particularly well adapted for computer vision applications such texture discrimination, edge detection, matching algorithms and fractal analysis.

SCORE
An Interactive, Graphic Interface to the GOALTENDER Language

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The animation of articulated figures, particularly humans, performing natural actions and tasks is a tedious and complicated process whether done by key-position techniques or dynamics models. One way to achieve succinct expression of desired activities is through constraints on the position and orientation of a figure and its sub-parts. The requirements for a constraint- based animation system and a language, GOALTENDER, are briefly described; they are the motivation for SCORE, an interactive graphic interface for GOALTENDER. GOALTENDER'S constraints include spatial regions, orientation zones, and time expressions. Within a constraint, "preferences" are described by weighted potential functions indicating the desirability of reaching various points, regions, or volumes of space. The relative importance assigned to multiple constraints is their "strength". SCORE is an interactive, graphic front end to GOALTENDER. It allows an animator to visualize the objects and people in a scene, their spatial relationships, and draws the regions and zones as they are used or defined for specific goals.

Searching for Information

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We consider the problem of constructing an intelligent, active sensor. Such a sensor is able to choose the number and placement of views needed to gather requested information while contending with noise processes, quantization and limitations of sensor scope. We outline an organization for an intelligent sensing system based on a statistical sensor model. A data structure similar to Koenderink and van Doorn's aspect graphs is developed as a local representation for information about the environment. Using ideas from decision theory, we formalize the tradeoff between the value of information and the cost of information.

We then state the basic expression for the optimal sensing strategy. This equation is generally not solvable in closed form. We simplify the problem by decoupling the choice of sample size from the choice of viewpoint. This allows the computation of the information value of various viewpoints with regard to the task at hand. We then show how game-theoretic techniques can be used to solve the problem of choosing a set of sensor views to maximize the information content of a sensor estimate. We discuss extensions of this work to multiple sensors, and the problem of intelligent search for information.

The Semantic Data Model and Large Information Requirements

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This project consists of the definition and construction of a frame-based representation language to allow transparent access to information that resides externally from the frame environment. The described programs comprise a semantically rich knowledge representation tool that provides access to both internally stored concepts and externally stored data from multiple databases and varying formats. Once the specific interfaces are built, the user need not be aware of the origin of the knowledge in the system due to the transparency that the interface provides.

Whereas some frame systems emphasize consistency and make it difficult to express many possible relational constructs, a design goal of DC **Representation Language** has been to include the ability to express anything possible about the world, including relationships among objects and among relationships themselves. Using only simple inheritance a regular contradiction-free network can be represented, but by using the additional semantic power inherent in DC **Representation Language** it is possible to construct nearly any relationship, however complex, that can be conjectured. Consistency is left as a task to be performed by the user of the system, sacrificed for the sake of completeness in concept description.

Optical Flow Using Spatiotemporal Filters

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GRASP LAB 116

A model is presented, consonant with current views regarding the neurophysiology and psychophysics of motion perception, that combines the outputs of a set of spatiotemporal motion-energy filters to estimate image velocity. A parallel implementation computes a distributed representation of image velocity that encodes both a velocity estimate and the uncertainty in that estimate. In addition, a numerical measure of image-flow uncertainty is derived; preliminary results indicate that this uncertainty measure might be used to recognize ambiguity due to the aperture problem. The model appears to deal with the aperture problem as well as the human visual system since it extracts the correct velocity for some patterns that have large differences in contrast at different spatial orientations. The model's capability for velocity discrimination is also comparable to that of the human visual system.

GUMS - A General User Modelling Shell

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This paper discusses the application of various kinds of default reasoning in systems maintain models of users. In particular, we describe the general architecture of a domain independent system for building and maintaining *long term models* of *individual users*. The user modelling system is intended to provide a well defined set of services for an *application system* interacting with various users, and has a need to build and maintain models of them. As the application system interacts with a user, it can acquire knowledge of him, and pass that knowledge on to the user model maintenance system for incorporation. We describe a prototype *general user modelling shell* (hereafter called GUMS) that we have implemented in Prolog. This system satisfies some of the desirable characteristics we discuss.

Modelling User Beliefs for Good Explanation

Robert Kass
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LINC LAB 82

An explanation facility is an important component of expert systems. However, the issues involved in producing good expert system explanations are not well understood. This paper discusses some features of good explanation, focusing on how a model of the user's beliefs is needed to produce understandable explanations, and on ways to acquire such a user model. The entire process of acquiring a user model and using it to generate explanations is illustrated with an extended example.

General User Modelling: A Facility to Support Intelligent Interaction

Robert Kass
and Tim Finin
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LINC LAB 83

An important component of adaptable interactive systems is the ability to model the system's users. Previous systems have relied on user models tailored to the particular needs of that system alone. This paper presents the notion of a *general user model*, and describes some of our research on building a general user modelling facility that could be used by a variety of applications. This work focuses on the representation, maintenance and acquisition issues of modelling long-term beliefs of the user, and describes a general facility for accomplishing these tasks.

A Medium-Complexity Compliant End Effector

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Recent interest in end effector design has not yet resulted in a versatile yet simple mechanism appropriate for a wide range of manipulation tasks. The design of a novel end effector underdevelopment at the University of Pennsylvania is explained in detail in this paper. The rationale supporting this mechanism is explored, its geometry is described, experimental results from the first prototype are shown, and some ideas for future work are presented.

The Need for User Models in Generating Expert System Explanations

Robert Kass
and Tim Finin
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LINC LAB 88

An explanation facility is an important component of an expert system. Current systems for the most part have neglected the importance of tailoring a system's explanations to the user. This paper explores the role of user modelling in generating expert system explanations, making the claim that individualized user models are essential to produce good explanation when the system users vary in their knowledge of the domain, or in their goals, plans, and preferences. To make this argument, a characterization of explanation, and good explanation is made, leading to a presentation of how knowledge about the user affects the various aspects of a good explanation. Individualized user models are not only important, they can be practically obtained. Acquiring a model of the user's beliefs, and using this model to tailor an explanation so that it is more understandable, is illustrated with an extended example. Finally, the problem of testing the effect of individualized user models on explanation generation is discussed, and possible experiments are described.

Cooperative Focus and Stereo Ranging

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GRASP LAB 119

This paper presents a cooperative computer vision procedure in which focus ranging and stereo ranging operate together, verifying the results of each other in computing the position (but not the shape) of arbitrary objects in a stationary, unknown enviornment. The procedure increases the reliability of the position measurements by enforcing measurement consistency via mutual constraint, and increases their accuracy by combining them with a maximum likelihood estimator into an estimate of lower variance than any of the measurements alone. The final outcome of the procedure is set of estimated three-dimensional points together with their estimated uncertainties built from a sequence of dynamic, adaptive sensing operations. The results of 75 experiments processing close to 3000 different object points lying between 1 and 3 meters distant from the cameras show that the integrated range values are (*i*) highly reliable, since no mistaken combined range measurements are observed, and (*ii*) more precise than either of the computed ranges alone. The cooperative methodology extends to more and different sensors, and the result lend practical credence to the view that multiple sensors (*i*) allow the limitations of a single sensor to be circumvented, (*ii*) provide larger, statistically more effective data sets, (*iii*) reduce mistakes generated by inaccurate interpretation models, using sensors outside of their known operating regions, and sensor failure.

Models for Motion Perception

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GRASP LAB 121

As observers move through the environment or shift their direction of gaze, the world moves past them. In addition, there may be objects that are moving differently from the static background, either rigid-body motions or nonrigid (e.g., turbulent) ones. This dissertation discusses several models for motion perception. The models rely on first measuring motion energy, a multiresolution representation of motion information extracted from image sequences.

The image flow model combines the outputs of a set of spatiotemporal motion-energy filters to estimate image velocity, consonant with current views regarding the neurophysiology and psychophysics of motion perception. A parallel implementation computes a distributed representation of image velocity that encodes both a velocity estimate and the uncertainty in that estimate. In addition, a numerical measure of image-flow uncertainty is derived.

The egomotion model poses the detection of moving objects and the recovery of depth from motion as sensor fusion problems that necessitate combining information from different sensors in the presence of noise and uncertainty. Image sequences are segmented by finding image regions corresponding to entire objects that are moving differently from the stationary background.

The turbulent flow model utilizes a fractal-based model of turbulence, and estimates the fractal scaling parameter of fractal image sequences from the outputs of motion-energy filters. Some preliminary results demonstrate the model's potential for discriminating image regions based on fractal scaling.

Using Powerdomains to Generalize Relational Databases

Peter Buneman and
Atsushi Ohori
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Much of relational algebra and the underlying theory of relational database design has an extremely simple representation in the theory of domains that is traditionally used in the denotational semantics of programming languages. By investigation the possible orderings on powerdomains that are well-known in the study of nondeterminism and concurrency it is possible to show that many of the ideas in relational databases apply to structures that are much more general than relations. This also suggests a method of representing data base objects as typed objects in programming languages.

In this paper we show how operations such as natural join and projection - which are fundamental to relational database design - can be generalized, and then give characterizations of functional dependencies and universal relations. All of these can be given a simple-minded semantics in terms of the underlying domains, which can be thought of as domains of partial descriptions of "real-world" objects. A final section discusses the application of database design theory to non-relational structures such as records with variants, higher-order relations, recursive structures and other ordered domains.

Visually-Guided Haptic Object Recognition

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GRASP LAB 122

Sensory capabilities are vital if a robot is to function autonomously in unknown or partially specified environments, if it is to carry out complex, roughly detailed tasks, and if it is to interact with and to learn from the world around it. Perception forms the all important interface between the cogitative organism and the world in which it must act and survive. Hence the first step toward intelligent, autonomous robots is to develop this interface – to provide robots with perceptual capabilities. This work presents a model for robotic perception. Within the framework of this model, we have developed a system which utilizes passive vision and active touch for the task of object categorization. The system is organized as a highly modularized, distributed hierarchy of domain specific and informationally encapsulated knowledge-based experts. The visual subsystem is passive and consists of a two-dimensional region analysis and a three-dimensional edge analysis. The haptic subsystem is active and consists of a set of modules which either execute exploratory procedures to extract information from the world or which combine information from lower level modules into more complex representations. We also address the issues of visually-guided haptic exploration and intersensory integration. Finally, we establish representational and reasoning paradigms for dealing with generic objects. Both representation and reasoning are feature-based. The representation includes both definitional information in the form of a hierarchy of frames and spatial/geometric information in the form of the spatial polyhedron.

Multiresolution Elastic Matching

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Matching of locally variant data to an explicit three dimensional pictorial model is developed for X-ray Computed Tomography scans of the human brain, where the model is a voxel representation of an anatomical human brain atlas. The matching process is three-dimensional without any preference given to the slicing plane. After global alignment the brain atlas is deformed like a piece of rubber, without tearing or folding. Deformation proceeds step-by-step in a coarse-to-fine strategy, increasing the local similarity and global coherence. The assumption underlying this approach is that all normal brains, at least at a certain level of representation, have the same topological structure, but may differ in shape details. Results show that we can account for these differences.

A Logical Analysis of Modules in Logic Programming

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LINC LAB 91

We present a logical language which extends the syntax of positive Horn clauses by permitting implications in goals and in the bodies of clauses. The operational meaning of a goal which is an implication is given by the deduction theorem: a goal $D \supset G$ is provable from a program P if the goal G is provable from the larger program $P \cup \{D\}$. This paper explores the qualitative nature of this extension to logic programming. For example, if the formula D is the conjunction of universally quantified clauses, we interpret the goal $D \supset G$ as a request to load the code in D prior to attempting G and then unload that code after G succeeds of fails. This extended use of implication provides a logical explanation of parametric modules, some uses of Prolog's assert

predicate, and aspects of abstract datatypes. Both a model theory and proof theory are presented for this logical language. In particular, we show how to build a Kripke-like model for programs by a fixed point construction and show that the operational meaning of implication mentioned above is sound and complete for intuitionistic logic. We also examine a weak notion of negation which is easily implemented in this language and show how database constraints can be represented by it.

Word-Order Variation in Natural Language Generation

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LINC LAB 92

In natural language generation the grammatical component has to be systematically interfaced to the other components of the system, for example, the planning component. Grammatical formalisms can be studied with respect to their suitability for generation. The tree adjoining grammar (TAG) formalism has been previously studied in terms of incremental generation. In this paper, the TAG formalism has been investigated from the point of view of its ability to handle word-order variation in the context of generation. Word-order cannot be treated as a last minute adjustment of a structure, a position not satisfactory both cognitively and computationally. The grammatical framework has to be able to deal with the word-order phenomena in a way such that it can be systematically interfaced to the other components of the generation system.

A Semantics for Complex Objects and Approximate Queries: Extended Abstract

Peter Buneman, Susan Davidson and Aaron Watters
MS-CIS-87-99

A new definition of complex objects is introduced which provides a denotation for incomplete tuples as well as partially described sets. Set values are "sandwiched" between "complete" and "consistent" descriptions (representing the Smyth and Hoare powerdomains respectively), allowing the maximal values to be arbitrary subsets of maximal elements in the domain of the set. We also examine the use of rules in defining queries over such objects.

A Performance Analysis of Timed Synchronous Communication Primitives

I. Lee and S. B. Davidson
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Two algorithms for timed synchronous communication between a single sender and single receiver are presented. Their performance is then analyzed, and their sensitivity to various parameters is discussed. These parameters include how long the processes are willing to wait for communication to be successful, how well synchronized the processes are, the assumed upper-bound on message delay, and the actual end-to-end message delay distribution. We conclude by discussing the fault tolerance of the algorithms.

Segmentation of 3-D Scenes Using Multi-Modal Interaction Between Machine Vision and Programmable, Mechanical Scene Manipulation

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GRASP LAB 124

The main idea in this dissertation is that one cannot discern the part-whole relationship of three-dimensional objects in a passive mode without a great deal of a priori information. Perceptual activity is exploratory, probing and searching. The main issue in active perception is control of the exploratory movements and the interaction between sensors and actions. Physical scene segmentation is the first step in active perception. The task of perception is greatly simplified if one has to deal with only one object at a time.

The thesis adapts the non-deterministic Turing machine model and develops strategies to control the interaction between sensors and actions for physical scene segmentation and perception. Scene segmentation is formulated in graph theoretic terms as a graph generation/decomposition problem. The isomorphism between the manipulation actions and graph decomposition operations is defined. The sensors generate the directed graphs representing the spatial relations among connected surface regions and the manipulator decomposes these graphs under sensor supervision. Assuming a finite number of sensors and actions and a goal state, that is reachable and measurable with the available sensors, the control strategies converge. Methods of perception via iteration and interaction of vision, manipulation, force/torque and other sensory data are presented.

No simulations were used in this thesis. Instead, an experimental system has been developed and integrated. This prototype consists of a vision system, a robot, an instrumented gripper equipped with force/torque and other sensors, several tools for manipulation, and a central computer/controller. The model has been tested in the USPS domain by applying

it to the problem of sorting irregular parcels (IPPs). Many experiments have proved the validity of the underlying theory. Furthermore, error recovery and convergence of the model has been experimentally verified in a real, noisy, and dynamic environment.

An Algorithm For Finding Canonical Sets of Ground Rewrite Rules in Polynomial Time

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LINC LAB 89

In this paper, it is shown that there is an algorithm which, given any finite set E of ground equations, produces a reduced canonical rewriting system R equivalent to E in polynomial time. This algorithm based on congruence closure performs simplification steps guided by a total simplification ordering on ground terms, and it runs in time $O(n^3)$.

A New Computational Structure For Real Time Dynamics

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GRASP LAB 126

In this paper we present a new structure for the computation of robot dynamics in real time. The basic characteristic of this structure is the division of the computation into a high priority synchronous task and a low priority background task. The background task computes the inertial and gravitational coefficients as well as the forces due to the velocities of the joints. Each control sample period, the high priority synchronous task computes the product of the inertial coefficients by the accelerations of the joints as well as performing the addition of the torques due to the velocities and gravitational forces. Kircanski (Kircanski86) has shown that the band-width of the variation of joint angles and their velocities is an order of magnitude less than the variation of the joint accelerations. This result agrees with the experiments that we have carried out on a PUMA260 robot.

Two main strategies have been adopted to reduce the computational burden of the dynamic equations. The first involves the selection of efficient algorithms for the computation of the equations. The second is the reduction in the number of dynamic parameters by identifying linear dependencies among parameters, as well as by making a significance analysis on the contribution of the parameters to the torques.

We chose an iterative procedure for the computation of the inertial and gravitational coefficients (Izaguirre86, Renaud85, Featherston84), and a recursive iteration for the computation of the velocity torques (Khalil86). In our experiments using the PUMA260 we obtained a set of 52 linearly independent parameters from an initial set of 78 parameters. The identification of the parameters revealed only 23 parameters to be significant.

These reductions permit the calculation of the inertias and gravitational coefficients, for the PUMA260 without load, with 98 multiplications and 70 additions; and the calcultion of the velocity torques with 140 multiplications and 110 additions. In the case of an arbitrary load at the end effector, the calculation of the inertias and gravitational coefficients require 190 multiplications and 150 additions and the velocity torques 200 multiplications and 170 additions. Velocity torques, inertial coefficients, and gravitational coefficients can be computed in the background in 20 milliseconds using an Intel 8087 microprocessor. The synchronous task requires only 6 multiplications and 6 additions per joint.

Type Inference In A Database Programming Language

Atsushi Ohori and Peter Buneman
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We extend a ML-like implicit type system to include a number of structures and operations that are common in database programming including sets, labeled records, joins and projections. We then show that the type inference problem of the system is decidable by extending the notion of a principal type scheme to include conditions on substitutions. Combined with Milner's polymorphic let constructor, our language also supports type inheritance. Existing approaches both to the problem of defining a type system for languages with inheritance and to that of inferring these types appear to be incomplete.

Implementing Theorem Provers In Logic Programming

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LINC LAB 87

Logic programming languages have many characteristics that indicate that they should serve as good implementation languages for theorem provers. For example, they are based on search and unification which are also fundamental to theorem proving. We show how an extended logic programming language can be used to implement theorem provers and other

aspects of proof systems for a variety of logics. In this language first-order terms are replaced with simply-typed λ-terms, and thus unification becomes higher-order unification. Also, implication and universal quantification are allowed in goals. We illustrate that inference rules can be very naturally specified, and that the primitive search operations of this language correspond to those needed for searching for proofs. We argue on several levels that this extended logic programming language provides a very suitable environment for implementing tactic style theorem provers. Such theorem provers provide extensive capabilities for integrating techniques for automated theorem proving into an interactive proof environment. We are also concerned with representing proofs as objects. We illustrate how such objects can be constructed and manipulated in the logic programming setting. Finally, we propose extensions to tactic style theorem provers in working toward the goal of developing an interactive theorem proving environment that provides a user with many tools and techniques for building and manipulating proofs, and that integrates sophisticated capabilities for automated proof discovery. Many of the theorem provers we present have been implemented in the higher-order logic programming language λ Prolog.

An Algebra of Communicating Time Dependent Processes

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GRASP LAB 127

The Timed Acceptance Model is an algebra for representing and analyzing time dependent processes. The Timed Acceptance model consists of a partially ordered domain of time dependent processes and a set of operators. A real-time process is defined by a set of timed traces and the nondeterministic choices it may make while executing. The partial ordering, called process containment, represents the notion of one process being less deterministic than another. The primitive operators are the standard CSP operators defined with respect to time. They represent the constructs needed in time dependent programming. The operators have various algebraic properties that are used in analyzing time dependent processes.

After presenting the algebra, we illustrate its use in specifying a time dependent system and analyzing its behavior.

Shape Recovery And Segmentation With Deformable Part Models

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A method for recovery of compact volumetric models for shape representation and segmentation in computer vision is introduced. The models are superquadrics with parametric deformations (bending, tapering, and cavity deformation). The input for the model recovery is three-dimensional range points. We define an energy or cost function whose value depends on the distance of points from the model's surface and on the overall size of the model. Model recovery is formulated as a least-squares minimization of the cost function for all range points belonging to a single part. The initial estimate required for minimization is the rough position, orientation and size of the object. During the iterative gradient descent minimization process, all model parameters are adjusted simultaneously, recovering position, orientation, size and shape of the model, such that most of the given range points lie close to the model's surface. Because of the ambiguity of superquadric models, the same shape can be described with different sets of parameters. A specific solution among several acceptable solutions, which are all minima in the parameter space, can be reached by constraining the search to a part of the parameter space. The many shallow local minima in the parameter space are avoided as a solution by using a stochastic technique during minimization. Segmentation is defined as a description of objects or scenes in terms of the adopted shape vocabulary. Model recovery of an object consisting of several parts starts by computing the rough position, orientation and size of the whole object. By allowing a variable number of range points in a model, a model can actively search for a better fit (by compressing itself and expanding) resulting in a subdivision of the object into a model representing the largest part of the object and points belonging to the rest of the scene. Using the same method, the remaining points can be recursively subdivided into parts each represented with a single compact volumetric model. Results using real range data show that the recovered models are stable and that the recovery procedure is fast.

Calculating Depth From Focus Using A Pyramid Architecture

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A method for recovering a depth map from an active focus analysis is presented. A sharpness map can be calculated for many small regions in an image using a Gaussian pyramid to sum the output of a Laplacian. The depth of each region can be recovered by examining the sharpness map over a range of focal positions. Real-time performance is achieved through hardware that computes Gaussian and Laplacian pyramids.

A Logic Programming Approach to Manipulating Formulas And Programs

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By permitting function and predicate symbols to be variables and by replacing first-order terms by simply typed lambda-terms, a higher-order extension to first-order Horn clauses can be described. To be complete in principle, a logic programming language based on this extension must incorporate higher-order unification. Although this is a more complex operation than first-order unification, its availability as a primitive makes certain kinds of programming tasks easier. We illustrate this aspect in the paper by presenting some programs in a higher-order version of Prolog called lambda Prolog that manipulate objects, such as formulas and programs, whose representation requires structures containing abstractions or bound variables. Specifically, we show (a) how a simple natural deduction theorem prover may be implemented in lambda Prolog, and (b) how some simple program transformers for a functional programming language may be written in this language. These programs exploit the availability of lambda-conversion and higher-order unification in lambda Prolog to provide elegant solutions to several awkward problems inherent in these tasks. We contend that programs which perform similar tasks but which are written in languages without these features would, at least, be much less perspicuous.

A Study of Tree Adjoining Grammars

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Constrained grammatical system have been the object of study in computational linguistics over the last few years, both with respect to their linguistic adequacy and their computational properties. A Tree Adjoining Grammar (TAG) is a tree rewriting system whose linguistic relevance has been extensively studied. A key property of these systems is that a TAG factors recursion from the co-occurence restrictions.

In this thesis, we study some mathematical properties of TAG's. We show that TAG's have several interesting properties and are a natural generalization of Context Free Grammars. We show equivalence of the classes of languages generated by TAG's with those generated by Head Grammars and a linear version of Indexed Grammars, which have been studied for their linguistic applicability. We define the embedded pushdown automaton, and extention of the pushdown automaton, and prove that they are equivalent to TAG's. We show that the class of Tree Adjoining Languages form a substitution closed abstract family of languages, and that each Tree Adjoing Language is a semilinear language. We show that a TAG can be parsed in polynomial time by adapting the Cocke-Kasami-Younger algorithm for CFL's.

Feature structures, essentially a set of atribute value pairs, have been used in computational linguistics to make statements of equality to capture some linguistic phenomena such as subcategorization and agreement. We embed TAG's in a feature structure based framework. We show that the resulting system has several advantages over TAG's. We give a mathimatical model of this system based on the logical calculus developed by Rounds, Kasper and Manaster-Ramer. Finally, we propose a restriction of this system and show how parsing of such a system can be done efficiently.

Three Highly Parallel Computer Architectures and Their Suitability for Three Representative Artificial Intelligence Problems

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MS-CIS-88-08
LINC LAB 97

Virtually all current Artificial Intelligence (AI) applications are designed to run on sequential (von Neumann) computer architectures. As a result, current systems do not scale up. As knowledge is added to these systems, a point is reached where their performance quickly degrades. The performance of a von Neumann machine is limited by the bandwidth between memory and processor (the *von Neumann bottleneck*). The bottleneck is avoided by distributing the processing power across the memory of the computer. In this scheme the memory becomes the processor (a "smart memory").

This paper highlights the relationship between three representative AI application domains, namely knowledge representation, rule-based expert systems, and vision, and their parallel hardware realizations. Three machines, covering a wide range of fundamental properties of parallel processors, namely module granularity, concurrency control, and communication geometry, are reviewed: the Connection Machine (a fine-grained SIMD hypercube), DADO (a medium-grained MIMD/SIMD/MSIMD tree-machine), and the Butterfly (a coarse-grained MIMD Butterfly-switch machine).

Tense as Discourse Anaphor

Bonnie Lynn Webber

MS-CIS-88-09
LINC LAB 98

In this paper, I consider a range of English expressions and show that their context-dependency can be characterized in terms of two properties:

1. they specify entities in an evolving model of the discourse that the listener is constructing;
2. the particular entity specified depends on another entity in that part of the evolving 'discourse model' that the listener is currently attending to.

Such expressions have been called *anaphors*. I show how tensed clauses share these characteristics, usually just attributed to anaphoric noun phrases. This not only allows us to capture in a simple way the oft-stated but difficult-to-prove intuition that *tense is anaphoric*, but also contributes to our knowledge of what is needed for understanding narrative text.

Specifying Theorem Provers In a Higher-Order Logic Programming Language

Amy Felty and
Dale Miller

MS-CIS-88-12
LINC LAB 99

Since logic programming systems directly implement search and unification and since these operations are essential for the implementation of most theorem provers, logic programming languages should make ideal implementation languages for theorem provers. We shall argue that this is indeed the case if the logic programming language is extended in several ways. We present an extended logic programming language is extended in several ways. We present an extended logic programming language where first-order terms are replaced with simply-typed λ-terms, higher-order unification replaces first-order unification, and implication and universal quantification are allowed in queries and the bodies of clauses. This language naturally specifies inference rules for various proof systems. The primitive search operations required to search for proofs generally have very simple implementations using the logical connectives of this extended logic programming language. Higher-order unification, which provides sophisticated pattern matching on formulas and proofs, can be used to determine when and at what instance an inference rule can be employed in the search for a proof. Tactics and tacticals, which provide a framework for high-level control over search, can also be directly implemented in this extended language. The theorem provers presented in this paper have been implemented in the higher-order logic programming language λ-Prolog.

Pronominal Reference to Events and Actions: Evidence from Naturally-Ocurring Data

Ethel Schuster

MS-CIS-88-13
LINC LAB 100

This report describes the analysis of data used to characterize pronominal references to events and actions. We studied two different sets of data and propose mechanisms that will support the generation of text including pronouns referring to events and actions.

Rigid *E*-Unification:
NP-Completeness and Applications
To Equational Matings
Jean Gallier, Paliath Narendran,
David Plaisted and Wayne Snyder
MS-CIS-88-14
LINC LAB 101

Rigid *E*-unification is a a restricted kind of unification modulo equational theories, or *E*-unification, that arises naturally in extending Andrews's theorem proving method of matings to first-order languages with equality. This extension was first presented in Gallier, Raatz and Snyder, where it was conjectured that rigid *E*-unification is decidable. In this paper, it is shown that rigid *E*-unification is NP-complete and that finite complete sets of rigid *E*-unifiers always exist. As a consequence, deciding whether a family of mated sets is an equational mating is an NP-complete problem. Some implications of this result regarding the complexity of theorem proving in first-order logic with equality are also discussed.

Theorem Proving Using Equational
Matings and Rigid *E*-Unification
Jean Gallier
Stan Raatz
Wayne Snyder
MS-CIS-88-15
LINC LAB 102

In this paper, it is shown that the method of matings due to Andrews can be extended to (first-order) languages with equality. It is also shown that this extension is both sound and complete. Checking that a family of mated sets is an equational mating is equivalent to the following restricted kind of *E*-unification.

GRADSIM: A Connectionist Network
Simulator Using Gradient
Optimization Techniques
Raymond L. Watrous
MS-CIS-88-16
LINC LAB 103

A simulator for connectionist networks which uses gradient methods of nonlinear optimization for network learning is described. The simulator (GRADSIM) was designed for temporal flow model connectionist networks. The complete gradient is computed for networks of general connectivity, including recurrent links. The simulator is written in C, uses simple network and data descriptors for flexibility, and is easily modified for new applications. A version of the simulator which precompiles the network objective function and gradient computations for greatly increased processing speed is also described. Benchmark results for the simulator running on the DEC VAX 8650, SUN 3/260 and CYBER 205 are presented.

Proof Explanation and Revision
Amy Felty and
Dale Miller
MS-CIS-88-17
LINC LAB 104

Proof structures in traditional automatic theorem proving systems are generally designed for efficiently supporting certain search strategies. They are not meant as a useful representation or presentation of complete proofs: usually only the experts who designed such systems can read them. As a result, complete proofs are of little value and are generally discarded. The failure of such systems to manipulate proofs as values of their own right is one reason why theorem proving systems have not found more use in artificial intelligence and mathematical software. In this paper, we present the design of the c-*proof system* which attempts to correct this failure of theorem proving systems. Proofs in c are represented by natural and flexible tree-structured deductions. These deductions make very good presentations of proofs, and c has a very simple mechanism for *lexicalizing* them into readable natural language text. Other proof structures, such as resolution refutations, are used to provide the information necessary for building such proof trees. A programming language based on an extension of LCF tactics and tacticals is available for writing programs which manipulate proof trees. Such programs include interactive proof editors and fully automatic theorem provers. Finally, c is capable of making substantial changes in the presentation of proofs: proofs can be revised or restructured in order to present their deductions in different styles. For example, proofs which contain uses of the indirect proof method can occasionally be automatically restructured into direct proofs.

Explaining Modal Logic Proofs
Amy Felty and Greg Hager
MS-CIS-88-18
LINC LAB 105

There has recently been considerable progress in the area of using computers as a tool for theorem proving. In this paper we focus on one facet of human-computer interaction in such systems: generating natural language explanations from proofs. We first discuss the c proof system—a tactic style theorem proving system for first-order logic with a collection of inference rules correspond-

ing to human-oriented proof techniques. In c, proofs are stored as they are discovered using a structured term representation. We describe a method for producing natural language explanations of proofs via a simple mapping algorithm from proof structures to text.

Nonclassical or specialized logics are often used in specialized applications. For example, modal logics are often used to reason about time and knowledge, and inheritance theories are often developed for classification systems. The form of, and explanations for, proofs in these systems should be tailored to reflect their special features. In this paper, we focus on the extension of c to incorporate proofs in modal logic, and on the different kinds of explanations of modal proofs that can be produced to meet the needs of different users.

Synthesizing Minimum Total Expansion Topologies for Reconfigurable Interconnection Networks

David Smitley and Insup Lee

MS-CIS-88-19
GRASP LAB 137

The performance of a parallel algorithm depends in part on how well the interconnection topology of the target parallel system matches the communication patterns of the algorithm. We describe how to generate a topology for a network that can be configured into any t-regular topology. The topology generated has small **total expansion** with respect to a given task graph. The **expansion** of an edge in a task graph is the length of the shortest path that the edge maps to in the processor graph. The algorithm used to generate the topologies is analyzed and its average case behavior is determined. In addition, this synthesis method is compared to the conventional approach of mapping a task graph onto a fixed processor topology.

Coherence and Consistency in Domains (Extended Outline)

Carl A. Gunter and Achim Jung

MS-CIS-88-20
LINC LAB 106

Almost all of the categories normally used as a mathematical foundation for denotational semantics satisfy a condition known as *consistent completeness*. The goal of this paper is to explore the possibility of using a different condition—that of **coherence**—which has its origins in topology and logic. In particular, we concentrate on those posets whose principal ideals are algebraic lattices and whose topologies are coherent. These form a cartesian closed category which has fixed points for domain equations. It is shown that a "universal domain" exists. Since the construction of this domain seems to be of general significance, a categorical treatment is provided and its relationship to other applications discussed.

Combining Algebra and Higher-Order Types

Val Breazu-Tannen

MS-CIS-88-21
LINC LAB 107

We study the higher-order rewrite/equational proof systems obtained by adding the simply typed lambda calculus to algebraic rewrite/equational proof systems. We show that if a many-sorted algebraic rewrite system has the Church-Rosser property, then the corresponding higher-order rewrite system which adds simply typed b-reduction has the Church-Rosser property too. This result is relevant to parallel implementations of functional programming languages.

We also show that provability in the higher-order equational proof system obtained by adding the simply typed b and h axioms to some many-sorted algebraic proof system is effectively reducible to provability in that algebraic proof system. This effective reduction also establishes transformations between higher-order and algebraic equational proofs, transformations which can be useful in automated deduction.

Active Perception

Ruzena Bajcsy

MS-CIS-88-24
GRASP LAB 136

Active Perception (Active Vision specifically) is defined as a study of Modeling and Control strategies for perception. By modeling we mean models of sensors, processing modules and their interaction. We distinguish local models from global models by their extent of application in space and time. The local models represent procedures and parameters such us, optical distortions of the lens, focal lens. spatial resolution. band-pass filter. etc. The global models on the other hand characterize the overall performance and make predictions on how the individual modules interact. The control strategies are formulated as a search of such sequence of steps that would minimize a loss function while one is seeking the most information. Examples are shown as the existence proof of the proposed theory on obtaining range from focus and stereo/vergence on 2D segmentation of an image and 3D shape parametrization.

Extensional Models For Polymorphism

Val Breazu-Tannen and Thierry Coquand

MS-CIS-88-25
LINC LAB 109

This is a slightly revised version of MS-CIS-87-75/LINC LAB 81. We present a general method for constructing extensional models for the Girard-Reynolds polymorphic lambda calculus-the polymorphic extensional collapse. The method yields models that satisfy additional, computationally motivated constraints like having only two polymorphic booleans and having only the numerals as polymorphic integers. Moreover, the method can be used to show that any simply typed lambda model can be fully and faithfully embedded into a model of the polymorphic lambda calculus.

Adaptive Image Segmentation

Helen L. Anderson, Ruzena Bajcsy and Max Mintz

MS-CIS-88-26
GRASP LAB 138

This paper introduces a general purpose scene segmentation system based on the model that the gradient value at region borders exceeds the gradient within regions. All internal and external parameters are identified and discussed, and the methods of selecting their values are specified. User-provided external parameters are based on segmentation scale: the approximate number of regions (within 50%) and typical perimeter:area ratio of objects of interest. Internal variables are assigned values adaptively, based on image data and the external parameters. The algorithm for region formation combines detected edges and a classical region growing procedure which is shown to perform better than either method alone. A confidence measure in the result is provided automatically, based on the match of the actual segmentation to the original model. Using this measure, there is confirmation whether or not the model and the external parameters are appropriate to the image data. This system is tested on many domains, including aerial photographs, small objects on plain and textured backgrounds, CT scans, stained brain tissue sections, white noise only and laser range images. The system is intended to be applied as one module in a larger vision system. The confidence measure provides a means to integrate the result of this segmentation and segmentations based on other modules. This system is also internally modular, so that another segmentation algorithm or another region formation algorithm could be included without redesigning the entire system.

Discourse Deixis: Reference to Discourse Segments

Bonnie Lynn Webber

MS-CIS-88-27
LINC LAB 110

Computational approaches to discourse understanding have a two-part goal: (1) to identify those aspects of discourse understanding that require process-based accounts, and (2) to characterize the processes and data structures they involve. To date, in the area of reference, process-based accounts have been developed for subsequent reference via anaphoric pronouns and reference via definite descriptors. In this paper, I propose and argue for a process-based account of subsequent reference via deictic expressions. A significant feature of this account is that it attributes distinct mental reality to units of text often called discourse segments, a reality that is distinct from that of the entities described therein.

Jacks: A Toolkit for Manipulating Articulated Figures

Cary B. Phillips and Norman I. Badler

MS-CIS-88-28
GRAPHICS LAB 20

The problem of positioning and manipulating three dimensional articulated figures is often handled by ad hoc techniques which provides a consistent and flexible user interface to a complex representation for articulated figures in a 3D environment. Jack is a toolkit of routines for displaying and manipulating complex geometric figures, and it provides a method of interactively manipulating arbitrary homogeneous transformations with a mouse. These transformations may specify the position and orientation of figures within a scene or the joint transformations within the figures themselves. Jack combines this method of 3D input with a flexible and informative screen management facility to provide a user-friendly interface for manipulating three dimensional objects.

A Logical Interpretation of Powerdomains

Carl A. Gunter

MS-CIS-88-31
LINC LAB 111

This paper characterizes the powerdomain constructions which have been used in the semantics of programming languages in terms of formulas of first order logic under a pre-ordering of provable implication. The goal is to reveal the basic logical significance of the powerdomains by casting them in the right setting. Such a treatment may contribute to a better understanding of their potential uses in areas which deal with concepts of

sets and partial information such as databases and artificial intelligence. Extended examples relating powerdomains to databases are provided. A new powerdomain is introducted and discussed in comparison with a similar operator from database theory. The new powerdomain is motivated by the logical characterizations of the three well-known powerdomains and is itself characterized by formulas of first order logic.

Task-Oriented Computer Animation of Human Figures

Norman I. Badler

MS-CIS-88-34

GRAPHICS LAB 21

The effective computer animation of human figures is an endeavor with a relatively short history. The earliest attempts involved simple geometries and simple animation techniques which failed to yield convincing motions. Within the last decade, both modeling and animation tools have evolved more realistic figures and motions. A large software project has been under development in the University of Pennsylvania Computer GRAPHICS Research Facility since 1982 to create an interactive system which assists an animator or human factors engineer to graphically simulate the task-oriented activities of several human agents. An interactive system called TEMPUS and its high performance successor is outlined which is intended to graphically simulate the task-oriented activities of several human agents. Besides an anthropometric database, TEMPUS offers multiple constraint-based joint positioning, dynamic simulation, real-time motion playback, a flexible three-dimensional user interface, and hooks for artificial intelligence motion control methods including hierarchical simulation, and natural language specification of movements. The overall organization of this project and some specific components will be discussed.

Preliminary Clinical Evaluation of Elastic Matching System

Robert Dann, John Hoford, Stane Kovacic, Martin Reivich and Ruzena Bajcsy

MS-CIS-88-35

GRASP LAB 142

In order to evaluate the performance of our elastic matching system, we have created a digitized atlas from a young normal male brain, using 135 myelin-stained sections at 700 micron spacing. Software was written to enter and edit regional anatomic contours, which were stacked and aligned to create a 3D atlas. We then evaluated the matching system by comparing computer generated contours with expert-defined contours for several subcortical structures, based on CT scans from six neurologically normal patients. The error in positioning, as defined by the distance between the centers of gravity, averaged 4.2 mm for the computer and 1.7 mm for the worst expert's reading, with the computer-drawn region frequently inscribed within that of the expert. Comparison was also made for each structure by determining the volume of overlap and the volumes not overlapping. On average, the computer's agreement with the experts was about 20 % less than the agreement among the experts. This was a preliminary test of the system using only subcortical structures. The results are promising, and techniques are being implemented to overcome the current deficiencies.

An Earley-Type Parsing Algorithm For Tree Adjoining Grammars

Yves Schabes and Aravind K. Joshi

MS-CIS-88-36

LINC LAB 113

We will describe and Earley-type parser for Tree Adjoining Grammars (TAG's). Although a CKY-type parser for TAGs has been developed earlier (Vijay-Shanker and Joshi, 1985), this is the first practical parser for TAGs because as is well known for CFGs, the average behavior of Earley-type parsers is superior to that of CKY-type parsers. The core of the algorithm is described. Then we discuss modifications of the parsing algorithm that can parse extensions of TAGs such as constraints on adjunction, substitution, and feature structures for TAGs. We show how with the use of substitution in TAGs the system is able to parse directly CFGs and TAGs. The system parses unification formalisms that have a CFG skeleton and also those with a TAG skeleton. Thus it also allows us to embed the essential aspects of PATR-II.

The Need For User Models in Generating Expert System Explanations

Robert Kass and Tim Finin

MS-CIS-88-37

LINC LAB 114

This is a revised version of MS-CIS-87-86/LINC LAB 88. An explanation facility is an important component of an expert system, but current systems for the most part have neglected the importance of tailoring a system's explanations to the user. This paper explores the role of user modelling in generating expert system explanations, making the claim that individualized user models are essential to produce good explanations when the system user vary in their knowledge of the domain, or in their

goals, plans, and preferences. To make this argument, a characterization of explanation, and good explanation is made, leading to a presentation of how knowledge about the user affects the various aspects of a good explanation. Individualized user models are not only important, it is pratical to obtain them. A method for acquiring a model of the user's beliefs implicitly by "eavesdropping" on the interaction between user and system is presented, along with examples of how this information can be used to tailor and explanation.

Domain Theoretic Models of Polymorphism

Thierry Coquand, Carl A. Gunter, and Glynn Winskel

MS-CIS-88-38

LINC LAB 115

We give an illustration of a construction useful in producing and describing models of Girard and Reynolds' polymorphic lambda-calculus. The key unifying ideas are that of a Grothendieck fibration and the category of continuous sections associated with it, constructions used in indexed category theory; the universal types of the calculus are interpreted as the category of continuous sections of the fibration. As a major example a new model for the polymorphic lambda-calculus is presented. In it a type is interpreted as a Scott domain. In fact, understanding universal types of the polymorphic lambda-calculus as categories of continuous sections appears to be useful generally. For example, the technique also applies to the finitary projection model of Bruce and Longo, and a recent model of Girard. (Indeed the work here was inspired by Girard's and arose through trying to extend the construction of his model to Scott domains.) It is hoped that by pin-pointing a key construction this paper will help towards a deeper understanding of models for the polymorphic lambda-calculus and the relations between them.

An Overview of λ-Prolog

Gopalan Nadathur and Dale Miller

MS-CIS-88-40

LINC LAB 116

λ-Prolog is a logic programming language that extends Prolog by incorporating notions of higher-order functions, λ-terms, higher-order unification, polymorphic types, and mechanisms for building modules and secure abstract data types. These new features are provided in a principled fashion by extending the classical first-order theory of Horn clauses to the intuitionistic higher-order theory of hereditary Harrop formulas. The justification for considering this extension a satisfactory logic programming language is provided through the proof-theoretic notion of a uniform proof. The correspondence between each extension to Prolog and the new features in the stronger logical theory is discussed. Also discussed are various aspects of an experimental implementation of λ-Prolog.

Redundant Multi-Modal Integration of Machine Vision and Programmable Mechanical Manipulation for Scene Segmentation

Constantine J. Tsikos and Ruzena K. Bajcsy

MS-CIS-88-41

GRASP LAB 144

The main idea in this paper is that one cannot discern the part-whole relationship of three-dimensional objects in a passive mode without a great deal of a priori information. Perceptual activity is exploratory, probing and searching. Physical scene segmentation is the first step in active perception. The task of perception is greatly simplified if one has to deal with only one object at a time.

This work adapts the non-deterministic Turing machine model and develops strategies to control the interaction between sensors and actions for physical segmentation. Scene segmentation is formulated in graph theoretic terms as a graph generation/decomposition problem. The isomorphism between manipulation actions and graph decomposition operations is defined. The non-contact sensors generate the directed graphs representing the spatial relations among surface regions. The manipulator decomposes these graphs under contact sensor supervision. Assuming a finite number of sensors and actions and a goal state, that is reachable and measurable with the available sensors, the control strategies converge. This was experimentally verified in a real, noisy, and dynamic environment.

Segmentation via Manipulation

Constantine J. Tsikos & Ruzena K. Bajcsy

MS-CIS-88-42

GRASP LAB 145

The motivation for this paper is the observation that a static scene that contains more than one object/part most of the time cannot be segmented only by vision or in general by any non-contact sensing. Exception to this is only the case when the objects/parts are physically separated so that the non-contact sensor can measure this separation or one knows a great deal of a priori knowledge about the objects (their geometry, material, etc.). We assume no such knowledge is available. Instead, we assume that the scene is reachable with a manipulator. Hence the problem represents a class of problems of segmentation

that occur on an assembly line, bin picking, organizing a desk top, and the like.

Second Interim Technical Report For Advanced Research in Range Image Interpretation for Automated Mail Handling

Ruzena K. Bajcsy, Kwangyoen Wohn, Franc Solina, Alok Gupta, Pramath Sinha, and Constantine J. Tsikos

MS-CIS-88-43

GRASP LAB 146

This is the report on range image interpretation of singulated Irregular parcels. The overall approach to this problem was to find the most general and generic method that will interpret the data, yet it is computationally economical. We have observed that the large majority of objects that are classified as Irregular Parcels are convex or can be modeled as such plus some deformation . Hence the primitive that we have chosen, is the superquadric model plus deformations such as tapering and bending along the major axis. The superquadric model is an analytic representation of volume of which cross-section is a class of curves varying between rectangular shape to elliptical one (of course circular and square shapes are included). As a side product of this representation we obtain naturally the position, orientation and the scale of the object. The principle of recognition is a fitting procedure which changes the parameters so to minimize the difference between the data and the volume of the model.

Speech Recognition Using Connectionist Networks

Dissertation Proposal

Raymond L. Watrous

MS-CIS-88-44

LINC LAB 117

The thesis of the proposed research is that connectionist networks are adequate models for the problem of acoustic phonetic speech recognition by computer. Adequacy is defined as suitably high recognition performance on a representative set of speech recognition problems. Seven acoustic phonetic problems are selected and discussed in relation to a physiological theory of phonetics. It is argued that the selected tasks are sufficiently representative and difficult to constitute a reasonable test of adequacy.

A connectionist network is a fine-grained parallel distributed processing configuration, in which simple processing elements are interconnected by scalar links. A connectionist network model for speech recognition has been defined called the temporal flow model. The model incorporates link propagation delay and internal feedback to express temporal relationships. The model is contrasted with other connectionist models in which time is represented explicitly by separate processing elements for each time sample.

It has been shown previously that temporal flow models can be 'trained' to perform successfully some speech recognition tasks. A method of 'learning' using techniques of numerical nonlinear optimization has been demonstrated. Methods for extending these results to the problems selected for this research are presented.

Enriching a Meta-Language with Higher-Order Features

John Hannan and Dale Miller

MS-CIS-88-45

LINC LAB 118

Various meta-languages for the manipulation and specification of programs and programming languages have recently been proposed. We examine one such framework, called natural semantics, which was inspired by the work of G. Plotkin on operational semantics and extended by G. Kahn and others at INRIA. Natural semantics makes use of a first-order meta-language which represents programs as first-order tree structures and reasons about these using natural deduction-like methods. We present the following three enrichments of this meta-language. First, programs are represented not by first-order structures but by simply typed lambda-terms. Second, schema variables in inference rules can be higher-order variables. Third, the reasoning mechanism is explicitly extended with proof methods which have proved valuable for natural deduction systems. In particular, we add methods for introducing and discharging assumptions and for introducing and discharging parameters. The first method can be used to prove hypothetical propositions while the second can be used to prove generic or universal propositions. We provide several example specifications using this extended meta-language and compare them to their first-order specifications. We argue that our extension yields a more natural and powerful meta-language than the related first-order system. We outline how this enriched meta-language can be compiled into the higher-order logic programming language lambda Prolog.

Uses of Higher-Order Unification for Implementing Program Transformers

John Hannan and Dale Miller

MS-CIS-88-46

LINC LAB 119

The application of higher-order terms to program

transformation has been explored for the case of source-to-source, correctness-preserving transformations of functional and iterative programs. The use of simply typed lambda-terms with higher-order variables provides a suitable representation (for effecting program transformations) of programs and program fragments. In this paper we consider some properties of higher-order unification and demonstrate how these properties may be exploited in implementing simple program transformers. We show how to implement, using a logic programming language extended with higher-order unification, several common transformers, e.g., unwind and unfold. We also consider the construction of a more involved transformer for doing a partial evaluation task. One goal of this paper is to address the formal correctness of program transformers rather than the correctness of the program transformations themselves. The latter subject has been addressed in numerous previous works but the former has received scarce attention. We argue that applying the techniques outlined in this paper produces lucid program transformers with straightforward correctness proofs. This is a significant step towards a better understanding of program transformers and their transformations.

Active Reduction of Uncertainty in Multi-Sensor Systems

Gregory D. Hager
MS-CIS-88-47
GRASP LAB 147

This dissertation addresses the problem of gathering and fusing information in multi-sensor systems. We formalize a decision-theoretic framework for information-gathering by defining four components: geometric models, sensor observation models, task models, and models of prior information. Geometric models consist of constrained collections of parametric surfaces. Sensor models mathematically describe the relationship between surface parameters and statistically corrupted sensor observations. Task models consist of a function relating geometry to requested task-specific information, and a utility describing how task performance degrades with inaccurate information. Prior information is encoded in a probability distribution over the parameter space.

Using game-theoretic techniques, we demonstrate that a commonly used fusion technique, minimum mean square estimation, is not adequate for the class of sensor models described by our framework. This motivates the development of a finite element method for computing an updated posterior distribution from a prior distribution and a sensor observation. The method accounts for sensor model uncertainty and geometric variations needed to match a surface to observed data. We show that the approximation error of the method is stable, and present simulation results for a variety of positioning and shape determination problems.

We then construct search procedures based on techniques developed in the field of experimental design. These procedures choose sensor actions which yield the best predicted performance of fusion for a given task. We first derive and discuss the sequential design method that we use; then show how to compute it efficiently, and demonstrate some of its properties through simulation. We also show how this method can be used to automatically stop sampling when the gains of gathering more data are outweighed by the costs.

Finally, we describe and demonstrate a working system based on these methods. This system uses controllable visual search and positioning to estimate the size and position parameters of polygonal objects, and the position, size and shape of superellipsoidal objects. We also discuss issues in extending our methods to multiple sensors, dynamically reconfigurable systems, and sensor planning using artificial intelligence methods.

Object Exploration Using a Parallel Jaw Gripper

A. Koutsou
MS-CIS-88-48
GRASP LAB 148

In this paper we present a system for tactile object exploration. The system is built using a gripper with two parallel fingers, each equipped with a tactile array and a force/torque sensor. We have designed and implemented a set of exploratory procedures for acquiring the following properties: weight, shape, texture, and hardness. The system is successful at extracting these properties from a limited domain of objects. We present a detailed evaluation of the system and the causes of its limitations. The manipulation, motion, and sensing primitives we have developed in the process of this work could be used for a variety of other tasks, such as model-based recognition, tool manipulation, and assembly.

Effective Control of Human Motion Animation

Diana T. Dadamo
MS-CIS-88-52
GRAPHICS LAB 22

In this paper, we describe TAKE_ONE, a parallel method of specifying human motion animation by a controlled mixture of values from three kinds of simulation: kinematic, dynamic, and constraint. In addition, tools to assist an animator to define qualities such as realism, individuality and expressiveness are developed.

The issues in comprehensive animation methods are explosion of complexity, difficulty in determining values of input parameters, and lack of ease in fine-tuning an animation. We discuss the advantages and issues involved in structuring the specification of an animation. We provide a structured method to use or to convert to, a parameterized motion definition. We introduce a method of specification to allow the development of the essential and minimal definitional qualities of an action. The result is that a reduction in run- time complexity and user-specification is effected and groundwork for an action database is done.

We develop techniques to refine kinematic animation specification so that it is more representative of actual positional goals and so that it is compatible with the use of the other methods. We provide a structure to systematically merge animations from the three methods, through user or program control, and provide an interface to an iterative method of definition and fine-tuning. Examples are provided to show the power of the TAKE_ONE method, including: an object placement example whose implementation is explained in detail, a wheel-turning task, and finally, a classical ballet pirouette which will serve as a goal example for our completed work.

Effective Control of Human Motion Animation

Norman I. Badler,
Barry B. Hunter, Jr.
and Cary Phillips
MS-CIS-88-54
GRAPHICS LAB 23

Bubblepeople are human figure models built from overlapping spheres. They provide a softer and more realistic representation of the human body than polygon-based models, require fewer primitives, and are easier to articulate. Unfortunately, displaying a body constructed entirely of spheres by conventional rendering techniques is relatively slow. A new slicing algorithm has been implemented which significantly decreases the time required to display solid shaded Bubblepeople as plygon models within a conventional scanline renderer.

Constraint-Based Temporal Planning

N. Badler, S. Kushnier and J. Kalita
MS-CIS-88-55
GRAPHICS LAB 24

This paper deals with the application of notions from "planning" and the "representation of temporal information" in an animation system to simulate human task performance. Specifically, a model was developed in which the representation and manipulation of temporal information forms the basis of a planning system. This model has been implemented as part of an animation system in which the goal was to enable a natural, clear language for the specification of relevant temporal constraints along with a planner that would manipulate these constraints, ultimately resulting in exact timing parameters to be passed to the low-level animation routines. The first part of the paper describes the essential role of temporal planning in an animation system that models human task performance. The second part of the paper goes on to explain how a wide variety of temporal constraints can be "compiled" into a set of low-level "simple constraints" through the use of "dummy intervals" and "fuzzy constraints." The third part of the paper describes how a definite "plan" of events can be generated based on an analogical "spring system."

Upper Bounds on Recognition of a Hierarchy of Non-Context-Free Languages

Michael Palis and Sunil Shende
MS-CIS-88-56
LINC LAB 122

Control grammars, a generalization of context-free grammars recently introduced for use in natural language recognition, are investigated. In particular, it is shown that a hierarchy of non-context-free languages, called the *Control Language Hierarchy* (CLH), generated by control grammars can be recognized in polynomial time. Previously, the best known upper bound was exponential time. It is also shown that CLH is in $NC^{(2)}$, the class of languages recognizable by uniform boolean circuits of polynomial size and $O(\log^2 n)$ depth.

Categories and Subject Descriptors: F.1.2. [**Computation by Abstract Devices**]: Modes of Computation - *alternation and nondeterminism, parallelism*; F.4.1. [**Mathematical Logic and Formal Languages**]: Formal Languages - *context-free grammars, control grammars*; I.2.7. [**Artificial Intelligence**]: Natural Language Processing - *language parsing*.

Segmentation versus object representation -- are they separable?

Ruzena Bajcsy, Franc Solina and Alok Gupta
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GRASP LAB 151

Relation between shape representation and segmentation is discussed to make an argument that they cannot be handled separately. Parameters that influence the selection of a particular shape representation scheme are identified and a control structure is proposed that employs shape models of different types and granularities in a coarse to fine strategy. The necessity of using different shape models is demonstrated by comparing object boundaries of volumetric models with actual occluding boundaries of objects in range images.

Parsing Strategies with 'Lexicalized' Grammars: Applications to Tree Adjoining Grammars

Yves Schabes, Anne Abeille and Aravind K. Joshi
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LINC LAB 126

In this paper, we present a parsing strategy that arose from the development of an Earley-type parsign algorithm for TAG's (Schabes and Joshi 1988) and from some recent linguistic work in TAGs (Abeille 1988a).

In our approach, each elementary structure is systematically associated with a lexical head. These structures specify extended domains of locality (as compared to a context-free grammar) over which constraints can be stated. These constraints either hold within the elementary structure itself or specify what other structures can be composed with a given elementary structure. The 'grammar' consists of a lexicon where each lexical item is associated with a finite number of structures for which that item is the head. There are no separate grammar of this form will be said to be 'lexicalized'.

We show that in general context-free grammars cannot be 'lexicalized'. We then show how a 'lexicalized' grammar naturally follows from the extended domain of locality of TAGs and examine briefly some the linguistic implications of our approach.

A general parsing strategy for 'lexicalized' grammars is discussed. In the first stage, the parser selects a set of elementary structures associated with the lexical items in the input sentence, and in the second stage the sentence is parsed with respect to this set. The strategy is independent of nature of the elementary structures in the underlying grammar. However, we focus our attention on TAG's. Since the set of trees selected at the end of the first stage is not infinite, the parser can use in principle any search strategy. Thus, in particular, a top-down strategy can be used since problems due to recursive structures are eliminated.

We then explain how the Earley-type parser for TAG's can be modified to take advantage of this approach.

Sublinear Parallel Time Recognition of Tree Adjoining Languages

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A parallel algorithm is presented for recognizing the class of languages generated by tree adjoining grammars, a tree rewriting system which has applications in computational linguistics. This class of languages is known to properly include all context-free languages; for example, the non-context-free sets $\{a^n b^n c^n\}$ and $\{ww\}$ are in this class. It is shown that the recognition problem for tree adjoining languages can be solved by a concurrent-read, exclusive-write parallel random-access machine (CREW PRAM) in $O(log^2(n))$ time using polynomially many processors. This extends a previous result for context-free languages.

Grouping Straight Line Segments In Real Images

Herve Poilve
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GRASP LAB 152

In this paper, we discuss straight line extraction as a part of the image interpretation process. Favoring the use of line drawings as intermediate data for the extraction, we survey the current methods, which all achieve a polygonal approximation of lines, and show that they are not appropriate for the identification of straight elements in a scene. We propose a new approach which uses a scale invariant criterion and is based on the characterization of prime segments in a line, and develop an original method for obtaining these prime segments. Results show that we significantly improve the performance of straight line extraction. The methodology we have used here is applicable to a large class of segmentation problems.

Multiresolution Representations and Wavelets

Stephane Mallat
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GRASP LAB 153

Multiresolution representations are very effective for analyzing the information in images. In this dissertation we develop such a representation for general purpose low-level processing in computer vision. We first study the properties of the operator which approximates a signal at a finite resolution. We show that the difference of information between the approximation of a signal at the resolutions 2^{j+1} and 2^j can be extracted by decomposing this signal on a wavelet orthonormal basis of $L(R^n)$. In $L^2(R)$, a wavelet orthonormal basis is a family of functions $[\ \overline{\sqrt{2^j}}\ \psi(2^j x+n)\ ]_{(j,n)\in Z^2}$, which is built by dilating and translating a unique function $\psi(x)$, called a wavelet. This decomposition defines an orthogonal multiresolution representation called a wavelet representation. It is computed with a pyramidal algorithm of complexity n log(n). We study the application of this signal representation to data compression in image coding, texture discrimination and fractal analysis. The multiresolution approach to wavelets enables us to characterize the functions $\psi(x) \in L^2(R)$ which generate an orthonormal basis.

The inconvenience of a linear multiresolution decomposition is that it does not provide a signal representation which translates when the signal translates. It is therefore difficult to develop pattern recognition algorithms from such representations. In the second part of the dissertation we introduce a nonlinear multiscale transform which translates when the signal is translated. This representation is based upon the zero-crossings and local energies of a multiscale transform called the dyadic wavelet transform. We experimentally show that this representation is complete and that we can reconstruct the original signal with an iterative algorithm. We study the mathematical properties of this decomposition and show that it is well adapted to computer vision. To illustrate the efficiency of this Energy Zero-Crossings representation, we have developed a coarse to fine matching algorithm on stereo epipolar scan lines. While we stress the applications towards computer vision, wavelets are useful to analyze other types of signal such as speech and seismic-waves.

On The Deformation of Image Intensity and Zero-Crossing Contours Under Motion

Jian Wu and K. Wohn
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GRASP LAB 154

Image intensity and edge are two major sources of information for estimating the motion in the image plane. The 2-D motion obtained by analyzing the deformation of intensity and/or edges is used to recover the 3-D motion and structure. In this paper we show that the motion defined by the image intensity differs from the motion revealed by the (zerocrossing) edge. Understanding of this discripancy is important since most of the 3-D motion recovery algorithms reported so far require accurate 2-D motion as their input.

We begin the discussion by assuming *the invariance of intensity*, that the evolution of image intensity manifests the underlying transformation of the image due solely to the motion of objects. We then raise the question if the zerocrossing of the Laplacian operating on the image intensity is invariant too. The change of perspective view due to relative motion results the zerocrossing not being preserved as the image evolves, thereby deteriorating the accuracy of the 2-D motion obtained from the zerocrossing contour. We derive how much the zero-crossing contour deviates from its "correct" position due to motion. The result may be used to determine the reliability of the zero-crossing contours for the purpose of the motion estimation.

Characterizing Structural Descriptions Produced by Various Grammatical Formalisms

K. Vijay-Shanker, David Weir and Aravind K. Joshi
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LINC LAB 129

We consider the structural description produced by various grammatical formalisms in terms of the complexity of the paths and the relationship between paths in the sets of structural descriptions that each system can generate. In considering the relationship between formalisms, we show that it is useful to abstract away from the details of the formalism, and examine the nature of their derivation process as reflected by properties of their *derivation trees*. We

find that several of the formalisms considered can be seen as being closely related since they have derivation tree sets with the same structure as those produced by Context-Free Grammars. On the basis of this observation, we describe a class of formalisms which we call Linear Context-Free Rewriting Systems, and show they are recognizable in polynomial time and generate only semilinear languages.

Characterizing Mildly Context-Sensitive Grammar Formalisms

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LINC LAB 132

This thesis involves the study of formal properties of grammatical formalisms that are relevant to computational linguists. The formalisms which will receive the most attention share the property that they are highly restricted in their generative power. Recent research suggests that Context-Free Grammars (CFG's) lack the necessary expressive power on which to base a linguistic theory. This has led computational linguists to consider grammatical formalisms whose generative power exceeds CFG's, but to only a limited extent. We compare a nubmer of formalisms on the basis of their weak generative capacity, as well as suggesting ways in which they can be compared on the basis of their strong generative capacity. In particular, we consider properties of their structural descriptions (or tree sets); and the types of dependencies (nested, crossed, etc.) that can be exhibited by each formalism.

Several formalisms that are notationally quite different (Tree Adjoining Grammars, Head Grammars, and Linear Indexed Grammars) have been shown to be weakly equivalent. We show that Combinatory Categorial Grammars are weakly equivalent to these formalisms. The class of languages generated by these formalisms can be though of one step up from CFG's, and we describe a number of progressions that illustrate this.

The string languages generated by TAL's, HL's, CCL's and LIL's exhibit limited crossed-serial dependencies in addition to those produced by Context-Free Grammars (nested and serial dependencies). By formalizing these crossed-serial dependencies and their relationship with the nested dependencies produced by CFG's we define an infinite progression of formalisms.

Our work on structural descriptions leads us to characterize a class of formalisms called Linear Context-Free Rewriting Systems (LCFRS's), which includes a wide range of grammatical formalisms with restricted power. The systems in this class have context-free derivations, and simple composition operations that are linear and nonerasing. We prove that all members of this family generate only semilinear languages that can be recognized in polynomial time.

Discourse Deixis and Discourse Processing

Bonnie Lynn Webber
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LINC LAB 133

Computational approaches to discourse understanding have two-part goal: (1) identifying those aspects of discourse understanding that require process-based accounts, and (2) characterizing the processes and data structures they involve. To date, in the area of reference, process-based accounts have been developed for reference via anaphoric pronouns and via definite descriptors. In this paper, I propose and argue for a process-based of deictic reference in text. This account adds precision to common notions of *discourse entity*, *disourse segment* and *focus* and to relationships between the three.

Combinatory Categorial Grammars: Generative Power and Relationship to Linear Context-Free Rewriting Systems

David J. Weir and
Aravind K. Joshi
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LINC LAB 134

Recent results have established that there is a family of languages that is exactly the class of languages generated by three independently developed grammar formalisms: Tree Adjoining Grammars, Head Grammars and Linear Indexed Grammars. In this paper we show that Combinatory Categorial Grammars also generates the same class of languags. We discuss the structural descriptions produced by Combinatory Categorial Grammars and compare them to those of grammar formalism in the class of Linear Context-Free Rewriting Systems. We also discuss certain extensions of Combinatory Categorial Grammars and their effect on the weak generative capacity.

RK: A Real-Time Kernel for a Distributed System with Predictable Response

Insup Lee, Robert King
and Richard Paul
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GRASP LAB 155

Robotics applications must execute in real-time. In addition, complex robotics applications include many physically distributed components such as manipulator arms and sensors. This paper presents the real-time kernel RK which is designed to facilitate the development of a distributed sensory system with muliple arms and sensors. The goal of the kernel is support distributed applications that require predictable timing behavior. Our kernel design guarantees predictable response times by scheduling processes and communications based on timing constraints. In addition, the kernel provides a set of primitives that can be used to implement applications requiring predicatble timing behavior. These primitives allow the specification of timing requirements that can be guaranteed in advance by the scheduler and the direct control of devices by application processes for faster and predictable feedback control. To illustrate the use of our kernel, this paper also describes a multiple sensory system which is being ported to our distributed test-bed.

Feature Structures Based Tree Adjoining Grammars

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LINC LAB 136

We have embedded Tree Adjoining Grammars (TAG) in a feature structure based unification system. The resulting system, Feature Structure based Tree Adjoining Grammars (FTAG), captures the principle of factoring dependencies and recursion, fundamental to TAG's. We show that FTAG has an enhanced descriptive capacity compared to TAG formalism. We consider some restricted versions of this system and some possible linguistic stipulations that can be made. We briefly describe a calculus to represent the structures used by this system, extending on the work of Rounds, and Kasper [Rounds et al. 1986, Kasper et al. 1986] involving the logical formulation of feature structures.

Timed Atomic Commitment

Susan Davidson, Insup Lee
and Victor Wolfe
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GRASP LAB 156

In a large class of hard-real-time control applications, components execute concurrently on distributed nodes and must coordinate, under timing constraints, to perform the control task. As such, they perform a type of atomic commitment. Traditional atomic commitment, however, is insufficient because there are no timing constraints. We therefore present a model and correctness criteria for *timed atomic commitment* (TAC) which requires the processes to be functionally consistent, but allows the outcome to include an exceptional state, indicating that timing constraints have been violated. A centralized timed two-phase commit protocol that adheres to these criteria is presented.

Modeling Reliable Distributed Real-time Programs

Victor Wolfe, Susan Davidson
and Insup Lee
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GRASP LAB 157

A model for distributed hard real-time programs should incorporate real-time characteristics and be capable of analyzing time-related reliability issues. We introduce a model called the Real-time Selection Resolution (RT-S/R) Model with these capabilities and demonstrate it by example.

Partial Computation in Real-Time Database Systems: A Research Plan

Susan B. Davidson
and Insup Lee
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GRASP LAB 158

State-of-the-art database management systems are inappropriate for real-time applications due to their lack of speed and predictability of response. To combat these problems, the scheduler needs to be able to take advantage of the vast quantity of semantic and timing information that is typically available in such systems. Furthermore, to improve predictability of response, the system should be capable of providing a partial, but correct, response in a timely manner. We therefore propose to develop a semantics for real-time database systems that incorporates temporal knowledge of data-objects, their validity, and computation using their values. This temporal knowledge should include not just historical information but future knowledge of when to expect values to appear. This semantics will be used to develop a notion of *approximate* or *partial computation*, and to develop schedulers appropriate for real-time transactions.

A Computational Analysis Of Line-Oriented Screw Transformations In Robotics

Janez Funda
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GRASP LAB 159

This paper contains a computational analysis and comparison of various representations of a general rigid body spatial screw displacement. Point transformations and line transformations are treated separately. In the context of point transformations, only a brief summary of the known techniques (i.e., *homogeneous transforms and quaternion/vector pairs*) and their computational behavior is given. Among line transformations, which comprise the primary focus of this paper, four mathematical formalisms for effecting a general spatial screw displacement are presented and analyzed in terms of computational efficiency in performing (a) general screw displacements of lines, and (b) compositions of screw displacement operators. Both sequential and parallel algorithms are given for each operation. The four formalisms considered are: (1) dual orthogonal 3 x 3 matrix, (2) dual unit quaternion, (3) dual special unitary 2 x 2 matrix, and (4) dual Pauli spin matrices. The conclusion reached is that quaternion/vector pairs are the most economical of the point transformation operators, whereas dual unit quaternions represent the most compact and most efficient line transformation formalism.

Formally Integrating Real-Time Specification and Implementation: a Research Proposal

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and Richard Gerber
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GRASP LAB 160

To show that a real-time system is correct with respect to a specification, we need to represent both the implementation and specification formally and prove that the implementation satisfies the specification. The proof of satisfaction requires a well-defined mapping between the implementation and specification. The proof of satisfaction requires a well-defined mapping between the implementation and specification models. Although several formal specification models have been developed, very little work has been done in formalizing implementation.

We propose to develop an integrated bi-level approach to the problem of reasoning about timing

properties of real-time systems. At the specification level, we plan to extend the Timed Acceptances model that we have developed. To formally represent an implementation, we will develop an implementation model, which is similar to our specification model, but captures many operational behaviors including process assignment, devices and assumptions on scheduling and clock synchronization. We will then integrate the two models by defining a well-founded map between them.

GRASP Lab Camera Systems and their Effecto on Algorithms

Helen L. Anderson
MS-CIS-88-85
GRASP LAB 161

Differences in information content between the horizontal and vertical directions in images produced in the GRASP Laboratory are discussed in this report. The differences are caused by spatial frequency response, pixel shape and data dependence. The response of an electro-optic system has been described based on the ability of a human observer to detect changes in intensity. However, when the observer is a machine rather than a human, directional dependence of the magnitude of intensity changes must be considered. The impact of directional dependence of information content on several basic image processing algorithms is discussed.

An Investigation of Language Input and Performance Timing for Task Animation

Jeffrey Esakov and Norman I. Badler
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GRAPHICS LAB 25

We describe a prototype system in which task animation is driven via natural language. The primary effort in developing the system is concentrated on the link between the natural language parser and the animation environment. Two primary problems are object referencing and specifying action durations. We describe a technique by which objects referenced by the parser can be correctly mapped to their geometric representation within the animation environment even though the internal representations may be vastly different. Furthermore, we show that results from experiments measuring human motor behavior can be applied to computer simulations to generate default task durations.

Exploratory Procedure for Computer Vision

Ruzena Bajcsy, K. Wohn and S.W. Lee
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GRASP LAB 165

This paper deals with Exploratory Procedures for Computer Vision. The assumptions are that we have a mobile camera system with controllable focus, close/open aperture, and ability of recording its position, orientation and movement. Furthermore we assume an unknown and unstructured environment. For our analysis we consider two types of illumination sources: the point source and the extended sky-like source. The exploratory procedures determine the illumination energy, in some cases the illumination orientation, the albedo and the differentiation between the true 3D scene and its picture. The key idea is the active mobile observer.

Comparative Analysis of Hill Climbing Mapping Algorithms

David L. Smitley and Insup Lee
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GRASP LAB 166

The performance of a parallel algorithm depends in part on how well the communication structure of the algorithm is matched to the communication structure of the target parallel system. The *mapping* problem is the problem of generating such a match algorithmically. Solving the mapping problem optimally for any non-trivial case is NP-complete. Therefore, a *heuristic* approach must be used to solve the problem. Although several heuristic algorithms to this problem have been developed, their performance has been evaluated on relatively few combinations of communication and processor structures. This paper extensively evaluates the performance of hill climbing mapping algorithms through simulation on communication structures representative of existing parallel algorithms and architectures. The motivations for our study are as follows: to establish the differences in performance between variations of the hill climbing heuristic; to determine the factors which affect the performance of hill climbing with respect to optimum; and to compare hill climbing to known optimum and non-optimum mappings to determine the effectiveness of hill climbing as a mapping heuristic.

Estimation of 3-D Motion and Structure Based on a Temporally-Oriented Approach With the Method of Regression

SiuLeong Iu and K. Wohn
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GRASP LAB 167

In this paper we argue that the 3-D velocity of a single point up to a scalar factor can be recovered from its 2-D trajectory under the perspective projection. We then extend the idea to the recovery of 3-D motion of rigid objects. In both cases measurements are collected through temporal axis first, while keeping the amount of measurements in each frame minimal. We may use muliple features to get a more accurate estimate if they are available. This approach called *temporally oriented approach* requires us to introduce the explicit model for the evolution of 3-D motion. Our analysis is based on the assumption that the 3-D motion is smooth so that its 3-D velocity can be approximated as a truncated Taylor series. Regression relations between unknown motion parameters and measurements for a single point and rigid body are derived. The method of Maximum Likelihood is used to estimate the motion. The uniqueness of determining the 3-D motion of a single point is discussed. Experimental results obtained from simulated data and real images are given to illustrate the robustness of this approach.

Comparative Studies Between Mechanical and Biological Tactile Sensors

Filip Fuma and
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GRASP LAB 169

The purpose of this paper is to realistically assess the performance we can expect from a robot equipped with tactile sensors. *It is our hypothesis that it is essential to* understand the physical properties of the sensor which delivers the information about the world to the robotic system. These properties determine the nature of subsequent processing, the data reduction algorithms, and finally, the world representation in the computer. We compare two methodologies - one coming from psychophysics and the other from engineering - and give, in one concrete example, some insights about the sensor and their implications.

Color in Computer Graphic Representation of Two-dimensional Parameter Distributions

Haim Levkowitz
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This dissertation investigates the hypothesis that *color increases the usefulness of computer graphic representations of two-dimensional parameter distributions.* The motivation is provided by the desirability of presenting multidimensional multiparameter medical images in the most useful way. The approach is justified by the multiparameter nature of color and the enhanced detectability of patterns in color environments.

A background of color and color models in computer graphics is presented. Several color models and the algorithms to transform between models are given.

The representation of a single parameter using color is discussed. Desirable properties of color scales are stated and the most commonly used color scales are described. The notion of an *optimal color scale* is introduced, and the development of a particular optimal color scale is described. For this task, a new algorithm—OPTIMAL-SCALES—is introduced. he linearization of color scales is discussed and a linearization algorithm—LOS—is presented. The result of the two-step process of applying these two algorithm is presented in the form of the Linearized-Optimal Color Scale (LOCS).

The representation of multiple parameters using color is discussed. A *generalized lightness, hue, and saturation (GLHS) color model* is proposed, which is a generalization of several of the previously presented color models and of which the existing models are special cases. They, as well as other possible models, are realized by different choices of values for parameters that characterize the general model. Transformation algorithms between the GLHS and the RGB models are given. GLHS-based color approaches for conveying multiparameter information are described. Criteria for the choice of a particular LHS special case are discussed. Uniformity is proposed as one criterion and the search for the most uniform LHS space is described.

The use of color in computer graphic representation of parameter distribution is investigated with emphasis on medical applications. Several potential medical applications are discussed for both single- and multiparameter information representation.

Observer performance experiments are conducted to study the merits of the proposed color methods. The results of the study show that observers performed better with a linearized gray scale than with the newly-developed LOCS at a statistically-significant level of confidence. They also show that observers performed better with the LOCS than with another color scale (the Heated-object scale), but at a non-significant level of confidence.

A Procedure for Characterizing Tactile Sensors

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GRASP LAB 171

We describe a methodology for the characterization of tactile sensors. We address the questions of verification of manufacturer's claims about the output of a sensor, reliability of the output and robustness of the sensor over time.

In our work with tactile sensors, it has become apparent that there is a need for a rigorous methodology of characterizing sensor quality.

We implement this as a procedure which is specific for the Lord LTS-200 sensor [ref 1] . With some modifications, this methodology could be applied to other tactile sensors.

Database Programming in Machiavelli - a Polymorphic Language with Static Type Inference

Atsushi Ohori, Peter Buneman and Val Breazu-Tannen
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Machiavelli is a polymorphically typed programming language in the spirit of ML, but supports a different kind of type inferencing that makes its polymorphism somewhat more general than that of ML and appropriate for database applications. In particular, a function that selects a field f of a records is polymorphic in the sense that it can be applied to any record which contains a field f with the appropriate type. When combined with a set data type and database operations including join and projection, this provides a natural medium for relational database programming. Moreover, by implementing database objects as reference types and generating the appropriate views -- sets of structures with "identity" -- we can achieve a degree of static type checking for object-oriented databases.

Acquiring a Model of the User's Beliefs from a Cooperative Advisory Dialog

Robert John Kass
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LINC LAB 139

A model of a user's beliefs is generally assumed to play an important role in supporting cooperative computer system behavior. Unfortunately, the basis for this assumption is not well-understood: it is not clear *what* information about the user is needed for systems to be cooperative, *how* that information is used, or how it can be *acquired*.

The first part of this thesis examines the importance of user models in generating cooperative expert system explanations, arguing that to produce an explanation the user is likely to understand, a system must reason about the user's domain knowledge. If a system is to interact with a range of users whose domain knowledge varies, then it will need explicit user models in order to produce understandable explanations tailored to individual users. This need is illustrated by several examples of how knowledge about a user's domain beliefs can affect the generation of expert system explanations.

Having initially established the role and importance of a user model in explanation generation, the remainder of the thesis focuses on a practical problem: how can a system acquire sufficient knowledge about the user to enable it to produce explanations he is likely to understand? Traditional approaches have depended on the explicit hand-coding of a large number of assumptions about the beliefs of anticipated system users—a tedious and error-prone process. This thesis proposes an *implicit* method for acquiring a user model, embodied in a set of implicit user model acquisition rules. These rules, developed from the study of a large number of transcripts of people seeking advice from a human expert, represent likely inferences that can be made about a user's beliefs—based on the system-user dialogue and the dialogue participants' previous beliefs. This implicit acquisition method is capable of quickly building a substantial model of the user's beliefs; a model sufficient to support the generation of expert system explanations tailored to individual users. Furthermore, the acquisition rules are domain independent, providing a foundation for a general user modelling facility for a variety of interactive systems.

Machine System For Exploration and Manipulation A Conceptual Framework and Method of Evaluation

Ruzena Bajcsy, Susan Lederman and Roberta L. Klatzky
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GRASP LAB 172

A conceptual approach to describing and evaluating problem-solving by robotic systems is offered. One particular problem of importance to the field of robotics, disassembly is considered. A general description is provided of an effector system equipped with sensors that interacts with objects for purposes of disassembly and that learns as a result. The system's approach is "bottom up," in that it has no a priori knowledge about object categories. It does, however, have pre-existing methods and strategies for exploration and manipulation. The sensors assumed to be present are vision, proximity, tactile, position, force and thermal. The system's capabilities are described with respect to two phases: object exploration and manipulation. Exploration takes the form of executing "exploratory procedures," algorithms for determining the substance, structure and mechanical properties of objects. Manipulation involves "manipulatory operators," defined by the type of motion, nature of the end-effector configuration and precise parameterization. The relation of the hypothesized system to existing implementations is described, and a means of evaluating it is also proposed.

The Relevance of Connectionism to AI: A Representation and Reasoning Perspective

Lokendra Shastri
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LINC LAB 140

In this paper it is argued that not only is connectionism relevant to knowledge representation and reasoning, but it also provides an ideal computational architecture for intelligent systems. To justify this claim, certain critical features that any computational architecture capable of supporting intelligent behavior must possess are identified, and then it is shown that the core features of connectionism correspond exactly to these features. It is also argued that connectionism cannot be viewed merely as an implementation paradigm because its core features influence our conceptions of representation and reasoning in important ways: designing connectionist models for solving complex tasks leads to the identification of constraints on the conceptual structure. The above issues are discussed with reference to two connectionist systems that perform certain reasoning tasks with extreme efficiency.

A Connectionist System for Rule Based Reasoning With Multi-Place Predicates and Variables

Lokendra Shastri and Venkat Ajjanagadde
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LINC LAB 141

McCarthy has observed that the representational power of most connectionist systems is restricted to unary predicates applied to a fixed object. More recently, Fodor and Pylyshyn have made a sweeping claim that connectionist systems cannot incorporate systematicity and compositionality. These comments suggest that representing structured knowledge in a connectionist network and using this knowledge in a systematic way is considered difficult if not impossible. The work reported in this paper demonstrates that a connectionist system can not only represent structured knowledge and display systematic behavior, but it can also do so with extreme efficiency. The paper describes a connectionist system that can represent knowledge expressed as *rules* and *facts* involving *multi-place* predicates (i.e., *n-ary* relations), and draw *limited*, but *sound*, inferences based on this knowledge. The system is extremely efficient - in fact, optimal, as it draws conclusions in time proportional to the *length* of the proof. It is observed that representing and reasoning with structured knowledge requires a solution to the *variable binding* problem. A solution to this problem using a *multi-phase* clock is proposed. The solution allows the system to maintain and propagate an arbitrary number of variable bindings during the reasoning process. The work also identifies constraints on the structure of inferential dependencies and the nature of quantification in individual rules that are required for efficient reasoning. These constraints may eventually help in modelling the remarkable human ability of performing certain inferences with extreme efficiency.

Qualitative Simulation of Ordinary and Intermittent Mechanisms (Ph. D. Dissertation)

Pearl Pu
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GRAPHICS LAB 26

Qualitative physics is an area in artificial intelligence which is concerned with the problem of describing how various physical devices work in a causal notion. In this thesis, we explore two fundamental issues in qualitative physics in the mechanical domain: 1) what are the ontological primitives needed to represent or describe both ordinary and intermittent mechanical devices in causal notions (the representation problem), and 2) how to construct a qualitative simulator to produce descriptions of the behavior of these devices (the simulation problem).

The first part of the thesis examines the requirements of the framework to be constructed. It was found that deKleer's device-based ontology suits our general criterion. That is, the structure of a device is to be expressed in terms of the device's constitutive subparts, and their behaviors. To extend his model to the mechanical domain, however, we propose several extra primitives. One of them, called the connection node, describes how a pair of objects are connected and how causality is achieved to propagate motion. The scheme that we propose can express the objects, connections, and power sources of a device.

In addition to the device-centered ontology as a general framework for our representation scheme, we define and analyze the concept of force and velocity flow. This notion is a certain way of describing the motion propagation in a device and provides several advantages which we will also discuss. One of which is

that it provides an unified way of describing dynamic and kinematic behaviors. Following this force and velocity flow model, we define a set of force and velocity propagation laws for three types of basic mechanical units, three types of basic mechanical connections and their subcases.

In the second part of the thesis, we investigate a method to simulate ordinary and intermittent mechanical mechanisms. We begin with definitions of constraint and flow graphs. We construct a step-by-step procedure to convert a physical device to its flow graph representation which is the input to our simulator. The simulator generates descriptions of a device's behavior in terms of how each object causes other objects to move and how objects change from one state to another. Three simulation algorithms are constructed for the case of forward-dynamic, energy-conserved, and kinematic systems respectively.

All the propagation laws, the flow graphs specification, and the three simulation algorithms have been implemented in a system called KREATOR. It is written in Flavors and Common Lisp on the Symbolics Lisp machines. Examples analyzed with KREATOR include the spring-block mechanism, gear trains, a two-mass spring mechanism, a spring-driven cam mechanism, a ratchet-paw mechanism, and a pendulum clock.

Real Time Inverse Kinematics With Joint Limits and Spatial Constraints

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A configuration of an articulated figure of joints and segments can sometimes be specified as spatial constraints. Constrained parts on the articulated figure are abstracted as end effectors, and the counterparts in the space are abstracted as goals. The goal (constraint) can be as simple as a position, an orientation, a weighted combination of position and orientation, a line, a plane, a direction, and so on, or it could be as complicated as a region in the space. An articulated figure consists of various segments connected together by joints has some degrees of freedom which are subject to joint limits and manual adjustment. This paper presents an efficient algorithm to adjust the joint angles subject to joint limits so that the set of end effectors concurrently attempt to achieve their respective goals. Users specify end effectors and goals: the program computes a final configuration in *real time* in the sense that actions appear to take no longer than actual physical activities would. If it is impossible to satisfy all the goals owing to the actual constraints, the program should end up with the best possibility according to the users' assignment of importances to each goal.

The Architecture of a Cooperative Respondent (Dissertation Proposal)

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If natural language question-answering (NLQA) systems are to be truly effective and useful, they must respond to queries *cooperatively*, recognizing and accommodating in their replies a questioner's goals, plans, and needs. Transcripts of natural dialogue demonstrate that cooperative responses typically combine several communicative acts: a question may be answered, a misconception identified, an alternative course of action described and justified. This project concerns the design of *cooperative response generation systems*, NLQA systems that are able to provide integrated cooperative responses.

Two questions must be answered before a cooperative NLQA system can be built. First, what are the reasoning mechanisms that underlie cooperative response generation? In partial reply, I argue that *plan evaluation* is an important step in the process of selecting a cooperative response, and describe several tests that may usefully be applied to inferred plans. The second question is this: what is an appropriate architecture for cooperative NLQA (CNLQA) systems? I propose a four-level decomposition of the cooperative response generation process and then present a suitable CNLQA system architecture based on the blackboard model of problem solving.

The Convergence of Mildly Context-Sensitive Grammar Formalisms

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Investigations of classes of grammars that are *nontransformational* and at the same time highly constrained are of interest both linguistically and mathematically. Context-free grammars (CFG) obviously form such a class. CFGs are not adequate (both weakly and strongly) to characterize some aspects of language structure. Thus how much more power beyond CFG is necessary to describe these phenomena is an important question. Based on certain properties of tree adjoining grammars (TAG) an approximate characterization of class of grammars, *mildly context-sensitive grammars* (MCSG), has been proposed earlier. In this paper, we have described the relationship between several different grammar formalisms, all of which belong to MCSG. In particular, we have shown that head grammars (HG), combinatory categorial grammars (CCG), and linear indexed grammars (LIG) and TAG are all weakly equivalent. These formalisms are all distinct from each other at least in the following aspects: (a) the formal objects and operations in each formalism, (b) the domain of locality over which dependencies are specified, (c) the degree to which recursion and the domain of dependencies are factored, and (d) the linguistic insights that are captured in the formal objects and operations in each formalism. A deeper understanding of this convergence is obtained by comparing these formalisms at the level of the derivation structures in each formalism. We have described a formalism, the linear context-free rewriting system (LCFR), as a first attempt to capture the closeness of the derivation structures of these formalisms. LCFRs thus make the notion of MCSGs more precise. We have shown that LCFRs are equivalent to multicomponent tree adjoining grammars (MCTAGs), and also briefly discussed some variants of TAGs, lexicalized TAGs, feature structure based TAGs, and TAGs in which local domination and linear

precedence are factored TAG(LD/LP).

Semantics of Types For Database Objects

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This paper proposes a framework of denotational semantics of database type systems and constructs a type system for complex database objects. Starting with an abstract analysis of the relational model, we develop a mathematical theory for the structures of domains of database objects. Based on this framework, we construct a concrete database type system and its semantic domain. The type system allows arbitrarily complex structures that can be constructed sing labeled records, labeled variants, finite sets and recursion. On the semantic domain, in addition to standard operations on records, variants and sets, a *join* and a *projection* are available as polymorphically typed computable functions on arbitrarily complex objects. We then show that both the type system and the semantic domain can be uniformly integrated in an ML-like programming language. This leads us to develop a database programming language that supports rich data structures and powerful operations for databases while enjoying desirable features of modern type systems of programming languages including strong static type-checking, static type inference and ML polymorphism.

Semantic Domains and Denotational Semantics

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LOGIC & COMPUTATION 04

This chapter discusses classes of mathematical structures suitable for use as the semantic domains of programming language constructs. Such structures play a significant role in the foundations of denotational semantics. Many categories of domains have been introduced to serve various purposes, but existing theories share several important characteristics. One such common concept is the view of *partial elements* provided by the theory. This concept of partiality is integral to the way the semantic domains we discuss can be used to model such programming language features as recursive definitions of functions and datatypes. Moreover, a theory of computability on abstract spaces requires a concept of *finite approximati* which is also provided by the theory of semanti omains. These concepts must be defined for spaces that maintain the desired level of abstraction while still providing an intuitive explanation of computability for functions, functionals, and such programming constructs as higher-order procedures, streams and so on.

Our goal is to discuss two classes of domains in some detail with an attempt to motivate the need for the conditions being imposed on the structures in computational terms. We have attempted to avoid heavy abstractions that would carry us too far afield, while trying to introduce the reader to several of the central concepts and techniques which are common to all of the approaches we might have taken.

A New Approach to Laboratory Motor Control MMCS The Modular Motor Control System

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Many projects within the GRASP laboratory involve motion control via electric servo motors, for example robots, hands, camera mounts and tables. To date each project has been based on a unique hardware/software approach.

This document discusses the development of a new modular, and host independent, motor control system, MMCS, for laboratory use. The background to the project and the development of the concept is traced.

An important hardware component developed is a 2 axis control motor control board that can be plugged into an IBM PC bus or connected via an adaptor to a high performance workstation computer.

To eliminate the need for detailed understanding of the hardware components, an abstract controller model is proposed. Software implementing this model has been developed in a device driver for the Unix operating system. However for those who need or wish to program at the hardware level, the manual describes in detail the various custom hardware components of the system.

Video-Rate Visual Servoing For Robots

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This paper presents some preliminary experimental results in robotic visual servoing, utilizing a newly available hardware region-growing and moment-generation unit. A Unix-based workstation in conjunction with special purpose video processing hardware has been used to visually close the robot position loop at video field rate, 60Hz.

The architecture and capabilities of the system are discussed. Performance of the closed-loop position control is investigated analytically and via step response tests, and experimental results are presented. Initial results are for 2 dimensional servoing, but extensions to 3 dimensional positioning are covered along with methods for monocular distance determination.

Intonation and Syntax in Spoken Language Systems

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The present paper argues that the notion of "*intonational structure*" as formulated by Pierrehumbert, Selkirk, and others, can be subsumed under the generalized notion of syntactic surface structure that emerges from a theory of grammar based on a "Combinatory" extension to Categorial

Grammar. According to this theory, the syntactic structures and the intonation structures of English are identical, and have the same grammar. Some simplifications appear to follow for the problem of integrating syntax and other high-level modules in spoken language systems.

Image Wavelet Decomposition and Applications

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The general problem of computer vision has been investigated for more than twenty years and is still one of the most challenging fields in artificial intelligence. Indeed taking a look at the human visual system can give us an idea of the complexity of any solution to the problem of visual recognition. This general task can be decomposed into a whole hierarchy of problems ranging from pixel processing to high level segmentation and complex objects recognition.

Contrasting an image at different representations provides useful information such as edges. First, we introduce an example of low level signal and image processing using the theory of wavelets which provides the basis for multiresolution representation. Like the human brain, we use a multiorientation process which detects features independently in different orientation sectors. So, we end up contrasting images of the same orientation but of different resolutions to gather information about an image.

We then develop an interesting image representation using energy zero crossings. We show that this representation is experimentally complete and leads to some higher level applications such as edge and corner finding, which in turn provides two basic steps to image segmentation. We also discuss the possibilities of feedback between different levels of processing.

Communicating Shared Resources: A Model for Distributed Real-Time Systems

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The timing behavior of a real-time system depends not only on delays due to process synchronization, but also on resource requirements and scheduling. However, most real-time models have abstracted out resource-specific details, and thus assume operating environments such as maximum parallelism or pure interleaving. This paper presents a real-time formalism called communicating Shared Resources (CSR). CSR consists of a programming language that allows the explicit expression of timing constraints and resources, and a computation model that resolves resource contention based on event priority. We provide a full denotational semantics for the programming language, grounded in our resource-based computation model. To illustrate CSR, we present a distributed robot system consisting of a robot arm and a sensor.

Abstractions in Logic Programs

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Most logic programming languages have the first-order, classical theory of Horn clauses as their logical foundation. Purely proof-theoretical considerations show that Horn clauses are not rich enough to naturally provide the abstraction mechanisms that are common in most modern, general purpose programming languages. For example, Horn clauses do not incorporate the important software abstraction mechanisms of modules, data type abstractions, and higher-order programming. As a result of this lack, implementers of logic programming languages based on Horn clauses generally add several nonlogical primitives on top of Horn clauses to provide these missing abstraction mechanisms. Although the missing features are often captured in this fashion, formal semantics of the resulting languages are often lacking or are very complex. Another approach to providing these missing features is to enrich the underlying logical foundation of logic programming. This latter approach to providing logic programs with these missing abstraction mechanisms is taken in this paper. The enrichments we will consider have simple and direct operational and proof theoretical semantics.

Part Description and Segmentation Using Contour, Surface and Volumetric Primitives (Dissertation Proposal)

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The problem of part definition, description, and decomposition is central to the shape recognition systems. The Ultimate goal of segmenting range images into meaningful parts and objects has proved to be very difficult to realize, mainly due to the isolation of the *segmentation* problem from the issue of *representation*. We propose a paradigm for part description and segmentation by integration of contour, surface, and volumetric primitives. Unlike previous approaches, we have used geometric properties derived from both boundary-based (surface contours and occluding contours), and primitive-based (quadric patches and superquadric models) representations to *define* and *recover* part-whole relationships, without *a priori* knowledge about the objects or object domain. The object shape is described at three levels of complexity, each contributing to the overall shape. Our approach can be summarized as answering the following question~: Given that we have all three different modules for extracting volume, surface and boundary properties, how should they be *invoked*, *evaluated* and *integrated*? Volume and boundary fitting, and surface description are performed in parallel to incorporate the best of the coarse to fine and fine to coarse segmentation strategy. The process involves feedback between the segmentor (the Control Module) and individual shape description modules. The control module *evaluates* the intermediate descriptions and formulates hypotheses about parts. Hypotheses are further tested by the segmentor and the descriptors. The descriptions thus obtained are independent of position, orientation, scale, domain and domain properties, and are based purely on geometric considerations. They are extremely useful for the high

level domain dependent symbolic reasoning processes, which need not deal with tremendous amount of data, but only with a rich description of data in terms of primitives recovered at various levels of complexity.

Control of Randomly Sampled Robotic Systems

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This paper studies control problems of sampled data systems which are subject to random sample rate variations and delays. Due to the rapid growth of the use of computers more and more systems are controlled digitally. Complex systems such as space telerobotic systems require the integration of a number of sub-systems at different hierarchical levels. While many sub-systems may run on a single processor, some sub-systems require their own processor or processors. The sub-systems are integrated into functioning systems through communications. Communication between processes sharing a single processor are also subject to random delays due to memory management and interrupt latency. Communications between processors involve random delays due to causal factors in measuring devices and to signal processing.

Traditionally, sampling rates are chosen to meet the worst case communication delay. Such a strategy is wasteful as the processors are then idle a great proportion of the time; sample rates are not as high as possible resulting in poor performance or in the over specification of control processors; there is the possibility of missing data no matter how low the sample rate is picked.

Randomly sampled systems have been studied since later 1950's, however, results on this subject are very limited and they are not applicable to practical systems. This paper studies asymptotical stability with probability one for randomly sampled multi-dimensional linear systems. A sufficient condition for the stability is obtained. This condition is so simple that it can be applied to practical systems. A design procedure is also shown.

These results are applied to robot control systems using PD controllers with a feedforward term, computed torque controllers or simple computed torque controllers. The effectiveness of the method is demonstrated by simulations.

Image Segmentation With Detection of Highlights And Inter-reflections Using Color

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We present an approach to the construction of a computational model for color image segmentation based on the physical properties of sensors, illumination lights and surface reflectances. Using the established model, we perform color image segmentation and detect small inter-reflections as well as highlights.